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Technology Development and Consumer Acceptance of Innovation in Fruit Production.

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Abstract

Precision Agriculture (PA) and the more specific branch of Precision Horticulture are two very promising sectors. They focus on the use of technologies in agriculture to optimize the use of inputs, so to reach a better efficiency, and minimize waste of resources.

This important objective motivated many researchers and companies to search new technology solutions. Sometimes the effort proved to be a good seed, but sometimes an unfeasible idea. So that PA, from its birth more or less 25 years ago, is still a "new" management, interesting for the future, but an actual low adoption rate is still reported by experts and researchers.

This work aims to give a contribution in finding the causes of this low adoption rate and proposing a methodological solution to this problem.

The first step was to examine prior research about Precision Agriculture adoption, by *ex ante* and *ex post* approach. It was supposed as important to find connections between these two phases of a purchase experience. In fact, the *ex ante* studies dealt with potential consumer's perceptions before a usage experience occurred, therefore before purchasing a technology, while the *ex post* studies described the drivers which made a farmer become an end-user of PA technology.

Then, an example of consumer research is presented. This was an *ex ante* research focused on pre-prototype technology for fruit production. This kind of research could give precious information about consumer acceptance before reaching an advanced development phase of the technology, and so to have the possibility to change something with the least financial impact.

The final step was to develop the pre-prototype technology that was the subject of the consumer acceptance research and test its technical characteristics.

SECTION 1

Drivers of Precision Agriculture Technologies Adoption: a Literature Review

1. Introduction

The adoption of new technologies in agriculture is rarely immediate. Even though much effort is placed into in persuading users to adopt new ICT tools, adoption is a complex activity and many factors influence these decision-making processes (Agarwal and Prasad, 1999; Dimara and Skuras, 2003).

Precision Agriculture is a fairly new concept of farm management developed in the mid-1980s and in this paper, the term “technology” includes the complete set of tools available for PA management (also called Precision Farming). The framework of PA focuses on a concept of fit between different variables: according to Pierce & Nowak (1999), PA provides the possibility to do the right thing, in the right place, at the right time and in the right way. Therefore, PA bases its applicability on the use of technologies to detect and decide what is “right” (Zhang et al., 2002).

Many aspects of PA have been studied, focusing on: relevant technologies, environmental effects, economic outcomes, adoption rates and drivers of adoption and non-adoption. Many authors have confirmed the environmental and economic benefits derived from PA (Batte and Arnholt, 2003; Pierce and Elliott, 2008; Swinton and Lowenberg-DeBoer, 1998). Nonetheless, a low rate of PA adoption is still reported by both academic surveys and professional reports (Ellis et al., 2010; Fountas et al., 2005; Lamb et al., 2008).

The adoption of PA technologies has been analyzed in both an *ex post* and *ex ante* context. *Ex post* studies have demonstrated the motives or reasons which have encouraged, and that are possibly still encouraging, farmers to adopt new PA technologies, while *ex ante* studies have permitted the analysis of the acceptance of a new technology prior its introduction. While a complete review of *ex post* papers has already been presented (Tey and Brindal, 2012), a more holistic review combining both *ex ante* and *ex post* analysis has not yet been made available.

Tey and Brindal (2012), excluding TAM and all the studies that had a predictive value from their review, overlooked the analysis of important drivers for decisions, since the perception of a new technology affects the behaviour towards it and consequently the intention to purchase it (Karahanna and Straub, 1999; Read et al., 2011).

Within the agricultural context, the analysis of both *ex post* and *ex ante* studies is useful to interpret the choices made by farmers when having to engage with new technologies and their adoption thereof (Bertschinger et al., 2012; Useche et al., 2012). This paper aims to evaluate the drivers of PA adoption by combining and comparing *ex ante* and *ex post* studies to elucidate possible relations between the two, simultaneously providing a more holistic and complete overview of the subject matter.

The paper is organized as follows: firstly, the methodology utilized in the review is presented; secondly, *ex ante* research is presented, focusing in particular on the technology acceptance model in PA; then, accounts of previous *ex post* research on PA technology adoption is provided; finally, possible conclusions are provided.

2. Data and Methods

According to Harts (1998), papers for this review were collected utilizing different combinations of sets of keywords in Scopus, "Precision agriculture adoption", "Technology adoption", "Technology acceptance", and "Precision Farming". More than one thousand papers and research outcomes were found. Then, research articles were filtered selecting only empirical studies published in peer-reviewed journals, and simultaneously excluding work focused only on policy, energy, and environmental issues. Eventually, 20 papers were selected and divided into two groups. Table 1 and Table 2 provide the list of the selected papers along with the details regarding data sources, sample sizes, and number of variables. The first group (Table 1) presents *ex ante* studies regarding the intention to adopt, and therefore the empirical setting of these papers consists of potential adopters of PA technologies. Research conducted prior to the adoption provided information about latent factors affecting attitudinal and behavioral aspects of potential users, that lead to certain choices such as whether or not to adopt a technology. The second group (Table 2) consists of articles evaluating PA adoption with an *ex post* approach, and thus considering the factors or drivers that have influenced adoption in groups of farmers that have already adopted a technology.

Methodologies used in 3 of the 7 *ex ante* papers were the evaluation of the willingness to pay (WTP), while in the other 4 papers authors followed the

Technology Acceptance Model, tested using Structural Equation Model or a Partial Least Square approach.

The Technology Acceptance Model (TAM) is an *ex ante* theoretical model that is widely used to explain the process of adopting new technology (Davis, 1989; King and He, 2006). It is a behavioral model derived from the Theory of Planned Behavior (Ajzen, 1991; Fishbein and Ajzen, 1975), that attempts to identify and test the relevance of certain factors in influencing a potential user's decision on how and when to utilize a new technology. Perceptual and attitudinal aspects of human behavior are the core constructs of TAM methodology, with the focus of this approach directed towards the attitude to adopt or the intention to use technology.

In the major part of the selected *ex post* papers, authors used a Logit Regression Model to identify which drivers were more significant in technology adoption.

The first analysis of these papers allowed to identify both *ex ante* and *ex post* variables influencing adoption of (or the intention to adopt) PA technologies. The second step focused on terminology used by the authors to define and explain the variables they found to be significant in determining PA technology adoption. Drivers and latent factors conceptually close to each other were gathered in a new upper level of factors affecting PA technology adoption, in common between *ex post* and *ex ante* studies. This simplification and further classification created three upper level factors named Competitive and Contingent Factors, Socio-demographic Factors, Financial Resources.

3. *Ex ante*

Table 1 includes 7 papers identified as *ex ante* studies. These predictive investigations reveal which drivers could affect the potential user's behavior before a decision is made to use – or not to use – a new PA technology. Three papers focus on the willingness to pay (Hite et al., 2002; Hudson and Hite, 2003; Marra et al., 2010); while the other four are based on TAM (Adrian et al., 2005; Aubert et al., 2012; Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010), focusing on the attitude to use a new PA device, which is positively correlated to the intention to adopt (Lee and Chang, 2011; Read et al., 2011).

Increasing profitability is the main motivation that stimulates the use of a new technology (Adrian et al., 2005; Aubert et al., 2012; Folorunso and

Ogunseye, 2008, 2008; Hite et al., 2002; Rezaei-Moghaddam and Salehi, 2010). In the TAM approach, a construct named Perceived Usefulness (PU) engages with this specific issue as it is defined as "the degree to which a person believes that using a particular system would enhance his or her job performance" (Davis, 1989).

Table 1. ***Ex ante*** **papers.**

N°	Ex-Ante Authors	Method	Data source	Sample Size	N° Var.
1	Hite et al., 2002	Partially censored probit model	Telephone survey in Mississippi	762	15
2	Hudson and Hite, 2003	Factorial design	Mail survey	423	14
3	Adrian et al., 2005	TAM and SEM	Survey in Alabama Extension meetings	85	7 constructs
4	Folorunso and Ogunseye, 2008	TAM and Regression analysis	Survey (Nigeria)	370	7 constructs
5	Marra et al., 2010	Dichotomous/Ordered polychotomous choice model Probit/Logit approach	Mail survey - Referendum contingent valuation approach	743	7 constructs
6	Rezaei-Moghaddam and Salehi, 2010	TAM and SEM	Survey to agricultural specialists (Iran)	249	7 constructs
7	Aubert et al., 2012	Partial Least Squares (PLS)	Survey to Quebec farm operators	438	15 constructs

The necessity to integrate new technologies in current practices, while avoiding adaptation processes, is another important theme emerging from the predictive research. This issue can be associated with another specific TAM construct, named Perceived Ease of Use (PEU): "the degree to which a person believes that using a particular system would be free of effort" (Davis, 1989). PEU can be influenced by other factors, such as education, previous experiences with other PA tools, the "early adopters" management style, and the availability of facilitating factors such as technical support or the possibility of a trial period with PA technology. These factors seem related, since a more educated person is more confident with, and more inclined towards the use of computer technologies (Adrian et al., 2005; Aubert et al., 2012; Hudson & Hite, 2003; Marra et al., 2010). Furthermore, the presence of experts about PA initiates a learning process, enabling potential users to become more aware and confident about PA tools, and thus promoting the perception of an “easy to use” technology (Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010). PEU is a construct that has been thoroughly investigated over time: it seems to be most influenced by factors represented by the “objective usability” of a technology and the “computer self efficacy” or “personal skills”, both a function of previous experience, education, external influence and support availability (Adrian et al., 2005; Folorunso and Ogunseye, 2008; Karahanna and Straub, 1999; Venkatesh, 2000).

The link between PEU, PU and Attitude to Adopt technologies shows variable patterns in literature:

1. In Adrian et al. (2005), the three constructs do not influence each other directly. Only PU has an indirect effect on the Intention to Adopt, mediated by Perceived Net Benefit;
2. In Folorunso and Ogunseye (2008),both PU and PEU affect the Attitude to Use, but the authors did not include the PEU-PU path;
3. Rezaei-Moghaddam and Salehi (2010) have verified that both PEU and PU have a direct effect on the Attitude to Use, but PEU has also an indirect effect (via PU) on the Attitude. Studies by Venkatesh (2000) demonstrated congruent results;
4. In Aubert et al. (2012), both PEU and PU directly affect the Adoption, while PEU has no direct effect on PU.

In contrast to the seminal research conducted by Davis (1989), 3 papers demonstrate that both PU and PEU have a significant effect on the Attitude to Use. This finding suggests that, in Precision Agriculture, the two features “Usefulness” and “Ease of Use” could be equally important in determining the success of a new PA technology. While Davis (1989) found that no amount of ease can compensate for a lack of usefulness, in converse a useful tool could be adopted even though it may not be so easy to use. In PA, a deficiency in one of the constructs is sufficient to negatively affect the potential users’ attitude towards adoption. The attitude to adopt a new PA technology is strongly affected by its costs, which can include a perception of both a high monetary cost or cost in the difficult use of technology, which can induce loss of a practitioner’s favour and impede PA diffusion.

Finally, the attitude to adopt new PA technologies is positively correlated to farm size. This supports findings that bigger and more profitable farms are more inclined to plan and invest money in new technologies, even in the current market situation, because PA technology is perceived as less expensive and affordable (Adrian et al., 2005; Hudson and Hite, 2003; Marra et al., 2010).

4. *Ex post*

The most important aspects influencing the adoption of PA technologies in the relevant literature were identified: farm size; total income; farmers' education; familiarity with computers; location. The typical PA adopter is indeed depicted as an educated farmer, owner of a larger farm with a good soil quality, and aiming to implement more productive agricultural practices to face growing competitive pressures. The adopter perceives the advantages of PA in terms of profitability and prefers to hire consultants, although he is already confident with the use of computers (Tey and Brindal, 2012). Farm size is the most frequently cited parameter affecting the use of new PA technologies. A farm can be defined as "large" if the total cultivable area is bigger than 500 hectares (Batte and Arnholt, 2003; Kutter et al., 2011), confirming the economy-of-scale benefits related to the implementation of PA technologies (the bigger the size, the greater the intention to purchase PA technologies). According to the examined papers, adopter's confidence with computers is the second most important driver affecting technology adoption. This factor embodies farmer's technological skills and in many cases it is derived from previous experiences with other PA devices.

A high level of farmer education, a high farm income and location are all mentioned in the literature with the same frequency as equally important factors for technology adoption. All parameters can improve a farmer's innovative capabilities through the acquisition of technological and entrepreneurial skills, as well as through the creation of a network of local relationships (Ascough II et al., 1999; Batte, 1999; Cioffi and Gorgitano, 1998).

Farmer's age has a variable effect on the decision to adopt PA tools (Tey and Brindal, 2012). In some cases, younger age was acknowledged as relevant for adoption as it possibly confers larger working horizons (D'Antoni et al., 2012; Kutter et al., 2011; Larson et al., 2008; Walton et al., 2008). On the contrary, some authors remarked that the difference between the age of adopters and non-adopters is inconsistent, even if significant, (Daberkow and McBride, 2003); finally, in some cases age is positively connected to the PA usage, therefore indicating that older farmers (over 50 years) are more likely to adopt new technologies (Torbett et al., 2007).

Table 2. ***Ex post*** **papers.**

N°	Ex-Post Authors	Method	Data source	Sample Size	N° Var.
1	Daberkow and McBride, 1998	Logit	USDA's 1996 ARMS	950	11
2	Khanna, 2001	Logit	2 Mail surveys	650+405	10; 11
3	Fernandez-Cornejo et al., 2002	Tobit	USDA's 1998 ARMS	4040	7
4	Roberts et al., 2002	Logit	Survey	284	10
5	Daberkow and McBride, 2003	Logit	USDA's 1998 ARMS	8429	11
6	Roberts et al., 2004	Probit	Survey of cotton farmers	1131	10
7	Torbett et al., 2007	Logit	Cotton farmers survey	1131	22
8	Isgin et al., 2008	Logit	Ohio PA survey	491	10
9	Larson et al., 2008	Logit	Cotton producer survey	1215	11
10	Walton et al., 2008	Probit	Cotton producer survey	827	13
11	Reichardt and Jürgens, 2009	Cross tabulation analysis	Mail and telephone survey	6183	5
12	D'Antoni et al., 2012	Logit	Mail survey to cotton farmers	1692	13
13	Robertson et al., 2012	Logit	4 surveys	1376	8

Other papers, not included in Tey and Brindal's (2012) review, have also studied the adoption of PA technologies and can enrich the "adopter" profile with some new characteristics. In Europe, although farmers did not quantify exactly the financial benefit(s) of using PA, 50% did perceive benefits associated with "the reduced need of fertilizers" and "a better knowledge of the field" (Reichardt and Jürgens, 2009). Another important result is that even the farmers who abandoned the use of PA are still optimistic about the profitability of precision agriculture in the future. Therefore, producers initially perceive considerable benefits associated with precision agriculture technologies; however the perception of value decreases as these technologies become increasingly routine and widespread (Walton et al., 2008). Although in Europe research about PA adoption is less widespread, evidence seems to support that farmers with college degrees working in or for larger companies are more inclined to use PA technologies (Reichardt and Jürgens, 2009), thus reaffirming the role of farm size and education in characterizing the potential PA technology user. However, small farms could become PA adopters thanks to contractors or cooperation (Kutter et al., 2011).

5. Construct Aggregation

In this section the constructs coming from both *Ex ante* and *Ex post* papers have been associated basing on its meaning and on the explanation provided by the authors. The result of this aggregation was the creation of three higher level groups (Competitive and Contingent Factors, Socio-Demographic Factors, and Financial Factors) both for *Ex ante* and for *Ex post* constructs.

Figure 1 and Figure 2 show the existing symmetry between *Ex ante* and *Ex post* constructs modeled on the basis of the three main aggregates:.

5.1 Competitive and Contingent Factors

This section covers all the factors and the drivers that were not directly determined by the farmers and/or are classifiable as environmental characteristics, such as Perceived Ease of Use, Facilitating Factors, Trialability/Observability, Geography and Soil Quality.

The first factor “Perceived Ease of Use”, as mentioned above has a double nature; the one considered here embodies the technical aspects of a technology. In this case a technology is easy-to-use because of its objective usability or compatibility with existing tools (Aubert et al., 2012); the intuitive way to use it or the easy learning process for using it (Venkatesh, 2000). In other words it reflects a good engineering project tailored to fit the farmer skills.

The variable “Facilitating Factors” takes its name from Folorunso and Ogunseye (2008), an *ex ante* research (but it also appears in some *ex post* studies); it indicates the importance of extension services and PA technology providers as sources of information about precision farming (Aubert et al., 2012; Daberkow and McBride, 2003, 1998; Folorunso and Ogunseye, 2008; Larson et al., 2008; Roberts et al., 2002; Robertson et al., 2012).

Figure 1. Ex ante constructs

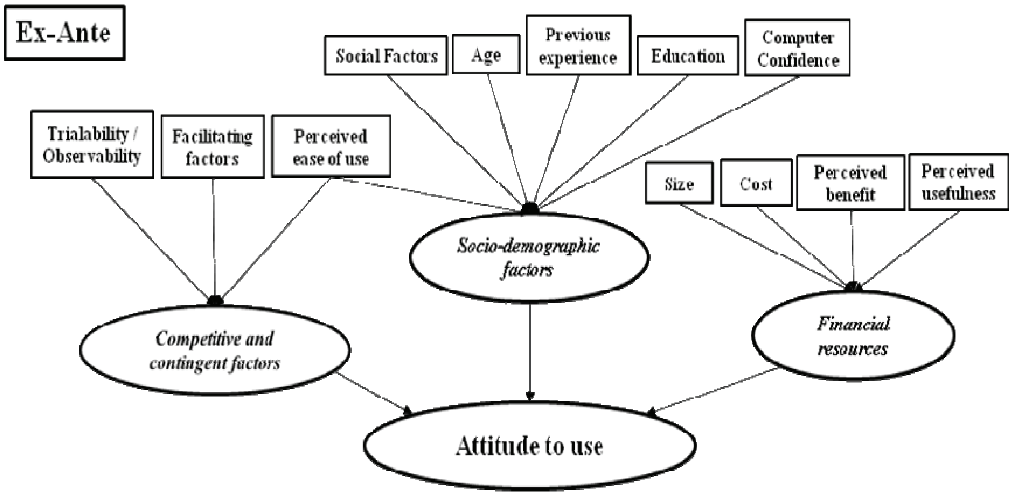
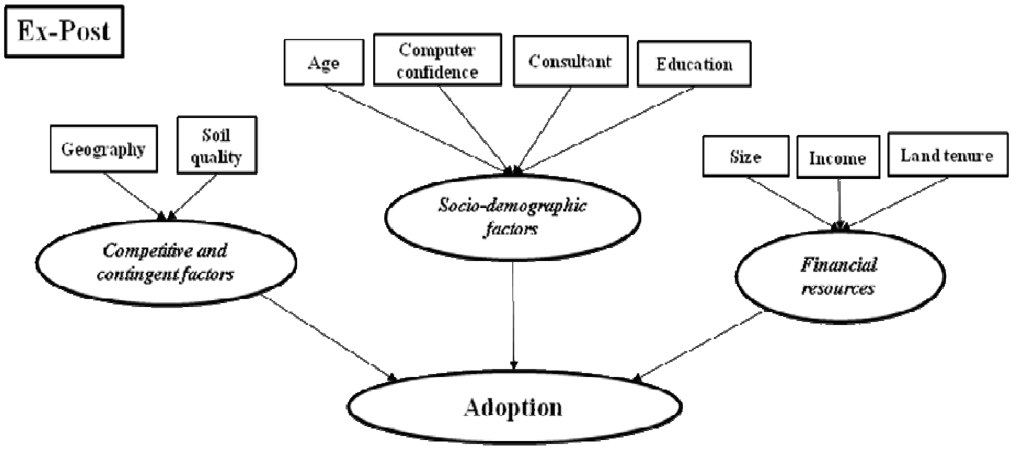


Figure 2. Ex post constructs.



Information arrives to the farmer as the result of a marketing campaign (built up by PA technology providers, dealers and vendors) or as the result of the work of Extension service agents or University researchers. In any case the aim of these different actors is to make farmers well-informed and confident with innovations in agriculture (Folorunso and Ogunseye, 2008).

Trialability and Observability are two attributes extracted from the theory of Diffusion of Innovations of Rogers (2003) and were evaluated in both *ex ante* and *ex post* sections (Aubert et al., 2012; Rezaei-Moghaddam and Salehi, 2010; Robertson et al., 2012). Trialability is defined as “the extent to which an innovation can be implemented on a limited basis to facilitate learning about its value”, while the definition of Observability is “the extent to which the outcomes of an agricultural innovation are visible to others” (Robertson et al., 2012).

Trialability and Observability are strictly connected to Facilitating Factors because they represent the result of the communication activity of the Extension services, researchers, and PA technology providers. After seeing in-field demonstrations of a new technology, farmers (i.e. potential users) will be more informed about the PA tools, and will perceive its usage as less risky and uncertain and with less negative consequences (Robertson et al., 2012).

Geography and Soil Quality are exclusively mentioned in *ex post* papers as variables indicating where the farm is located (country, state/region, county/province) and the soil fertility, respectively. While the Soil Quality is simply and positively related to PA technology adoption (Isgin et al., 2008; Khanna, 2001; Roberts et al., 2004), living in a specific state or place constitutes a dummy variable that acts as a proxy of adoption. The meaning of this driver is that the closer the proximity to PA technology dealers, the more the farmer will likely adopt a PA technology (Daberkow and McBride, 2003, 1998; Isgin et al., 2008; Khanna, 2001; Larson et al., 2008; Roberts et al., 2004).

5.2 Socio-Demographic Factors

This section considers the following variables: Perceived Ease of Use, Social Factors, Previous Experience, Consultant, Age, Education, and Computer Confidence. In particular, the last three are both *ex post* drivers and *ex ante* variables.

This group represents the factors determined by the farmer and by the interaction between farmer and environment: what the farmer has learned during his life both on his own and through the relationships he has built within his community, in other words his skills and his beliefs.

Perceived Ease of Use was already reported both in the previous and in *ex ante* chapters, but here it expresses the personal skills a farmer developed, thanks to previous experience, education, external influence and support availability (Adrian et al., 2005; Folorunso and Ogunseye, 2008; Karahanna and Straub, 1999; Venkatesh, 2000). For example, a yield mapping technique is perceived as an easy-to-use technology by younger, more educated and already computer confident farmers, because these personal characteristics that have led to adoption are the same which had led to awareness before the using experience (Adrian et al., 2005; Daberkow and McBride, 2003; Folorunso and Ogunseye, 2008).

Social Factors is a variable extracted from Folorunso and Ogunseye (2008). It is defined as "the person's conception of what he or she should do" and it reflects the pressure coming from society and the neighborhood in order to stimulate the use of PA technology (Hite et al., 2002; Isgin et al., 2008). The external influence could affect farmer behavior, particularly when the farmer has a positive view about the future of PA technologies, therefore the combination of external pressure with personal belief acts as propellant in the effort to find new information about PA technologies available and to increase his knowledge (D'Antoni et al., 2012; Larson et al., 2008). The farmer's knowledge has a strong effect in determining the ease of use of a PA technology, in particular in avoiding the perception of a technology cumbersome and difficult to use (Aubert et al., 2012). The introduction of PA technologies in the current agricultural practice requires higher skills than actually possessed by farmers; farmers need more information to learn to use PA technologies and education programs have been organized in order to train farmers and so increase their expertise (Aubert et al., 2012; Larson et al., 2008; Reichardt and Jürgens, 2009; Roberts et al., 2004).

The "Consultant" driver could effectively represent the *ex post* version of "Social Factors" because it was found that farmers who hired consultants or relied on Extension services and Universities as a source of information about PA technologies are more likely to become adopter (Daberkow and McBride, 2003, 1998; Larson et al., 2008; Roberts et al., 2002; Robertson et al., 2012).

5.3 Financial Factors

This section includes Farm Size, Perceived Usefulness, Perceived Benefit, Cost, Income, Land Tenure. Farm size is a variable emerging from both *ex ante* and *ex post* sections, so it is the most cited driver affecting adoption and attitude to adopt; while Perceived Usefulness, Perceived Benefit and Cost are exclusively *ex ante*, and Income, Full Time Farmer, Ownership and Tenure are *ex post*. The linkage among these factors and drivers is that they were determined by the farmer's managerial skills. Financial Factors are all those financial and economical aspects that moved a farmer to purchase a PA technology (*ex post*) or probably could influence a future usage (*ex ante*).

A large farm could have been inherited and/or the fruit of a good managerial practice; however, it is a "financial factor" because the total land area, other than having a value of its own, implies that PA technologies adoption is actually more convenient in a larger rather than in a smaller farm , on the basis of the economy-of-scale rule (Adrian et al., 2005; D'Antoni et al., 2012; Daberkow and McBride, 2003; Isgin et al., 2008; Khanna, 2001; Larson et al., 2008; Marra et al., 2010; Robertson et al., 2012).

Perceived Usefulness and Perceived Benefit, according to the original definition given by Davis (1989) and Adrian et al. (2005) respectively, represent the benefits expected by potential users because of adoption of a PA technology. Among the whole set of benefits, the economical one is the most important and could be summarized as an expected better job performance and a positive benefit/cost ratio.

The perception of PA technologies as costly technology is a very important aspect that is recognized to slow down and limit the PA diffusion process. Especially in Europe PA technology is perceived more expensive than in other countries because of the smaller farm size (Reichardt and Jürgens, 2009), but even in the rest of the world a public subsidization is necessary to spread PA technology adoption (Hudson and Hite, 2003; Marra et al., 2010). Adding to this, some authors even suggest that "reducing voluntariness and increasing the constraints would likely increase adoption" (Aubert et al., 2012).

As a consequence of the high cost of PA technologies, farm Income turned out to be a driver capable of affecting PA technology adoption and it was found to be significant in *ex post* studies. It was represented as Net Income (Daberkow and McBride, 2003; Walton et al., 2008), or as Farm sales or the ratio between debt and total asset (Isgin et al., 2008).

The last driver that could influence PA technology adoption is Land Tenure. Past research was not unequivocal in findings, but it seems that renters are more likely to adopt PA technologies than owners, because of a lack of knowledge about the land they farm and the willingness to take the maximum advantage from that (Daberkow and McBride, 2003; Khanna, 2001; Roberts et al., 2002; Torbett et al., 2007).

6. Discussion and Conclusion

The integration of *ex ante* and *ex post* approaches yields a symmetrical structure of factors that influence PA adoption, as shown in Figure 1. The presence of similar constructs confirms that TAMs can be a feasible method to understand the attitude towards adoption. When first considering attitude towards PA technologies, we find two groups of farmers: those who show a positive attitude towards the use of PA technologies represent the actual potential market for PA; the non-adopters instead represent the share of farmers that today constitutes the non-market. Non-adopters do not have sufficient skills and competence to manage PA tools, or lack the financial resources to purchase them. They have specific perceptions about Usefulness and Ease of Use of these technologies.

Farmers appreciate in-field demonstrations, free trials, support services related to the use of new technologies, as they promote the perception that the use of a technology is easy (Folorunso and Ogunseye, 2008; Kutter et al., 2011; Larson et al., 2008). Moreover, the intrinsic simplicity of the new technology is fundamental to avoid an incompatibility among PA tools, and difficulties in simultaneously utilizing and managing different technological devices (Sassenrath et al., 2008; Swinton and Lowenberg-DeBoer, 1998).

Studies conducted using TAMs demonstrate that both Usefulness and Ease of Use are central aspects for technology adoption, provided that these aspects do not cause a significant increase in the production cost (Hudson and Hite, 2003; Marra et al., 2010; Reichardt and Jürgens, 2009; Robertson et al., 2012).

The diffusion process of technology was explained by Beal and Bohlen (1955) and Rogers (1962): Awareness, Interest, Evaluation, Trial, Adoption; and we always can see Innovators, Early Adopters, Early Majority, Late Majority and Laggards. The process that leads from awareness to decision to adopt a new technology is the same for Innovators as for Laggards, but the actors' characteristics account for the difference in the time of adoption (Wejnert, 2002).

It is possible to assign factors emerged from this review to each phase of the Diffusion Process.

1. Awareness accounts for social factors, education, computer confidence, geography.
2. Interest: perceived usefulness, perceived ease of use.
3. Evaluation: size, soil quality, income, cost, previous experience, age.

4. Trial: trialability, observability, facilitating factors, perceived benefit, perceived ease of use.
5. Adoption: attitude to adopt, intention to adopt, adoption rate.

Besides, in order to reach wider PA technology diffusion, the starting point is to really understand which are the problems that afflict farmers. Researchers, producers and providers of PA technologies must be sure to have solutions for farmers' problems. PU and PEU must be satisfied at the same time. The challenge now is to really understand what is Useful for farmers. A common error among vendors is first to be certain to have a solution and then look for problems to solve. The correct way is starting from understanding problems and then finding and proposing a solution.

Two aspects emerge that stakeholders should consider. There are two alternative policies or two ways to solve the problem of a low adoption rate. The first option requires improving farmers' expertise, a "push" policy that takes all the information about PA technologies to the farmers and their co-workers; providers and dealers must work side-by-side with researchers and Extension agents in order to find the right solution for farmers' problems. Then, high investment in training, demonstration and promotion is needed.

The second option is to deal with the largest part of farmers, the non-adopters. It means forming a non-adopter profile too: a farmer with lower education, either large or small farm, of any age, not computer confident. Non-adopters could have the same problems of the typical adopter but different characteristics, and to satisfy their request different technologies are necessary. From the literature a list of suggestions emerge: an extremely cheap PA technology, easy to learn, well compatible with other instruments, providing essential data easy to interpret (that could mean a lower performance device but not in terms of quality of information) (Aubert et al., 2012; Larson et al., 2008; Reichardt and Jürgens, 2009; Robertson et al., 2012).

In conclusion, as suggested by some researchers, a new small market should be created. Considering that the PA market is still small and in its juvenile stage, it offers a considerable opportunity for skilled people with knowledge and expertise in this field. The specific features of the sector that have been described as weaknesses, with the correct know-how, can be turned into opportunities, and can furthermore be interpreted as an incentive to create small firms providing consultancy other than simply the sale of the technologies (Jochinke et al., 2007).

SECTION 2

Fruit Growers' Perceptions towards Technology Innovation.

1. Introduction

1.1 Precision Fruit Growth Management

Precision Agriculture (PA) or Precision Farming (PF) is an Agricultural Management Practice that focuses on the usage of new technology in order to optimize profits and benefits for farmers, the environment and consumers (Pierce and Nowak, 1999; Zhang et al., 2002).

Precision Farming applied to fruit orchards and vineyards was developed more recently than Precision Farming on field crops, therefore it is still not so widely adopted.

Precision Viticulture probably attracted more attention than other fruit crops sooner, but Precision Farming Management both in vineyards and in fruit tree orchards consists of zoning and monitoring fruit production, fruit quality, pest disease, water status, etc… with local and remote sensors in order to create yield maps and to manage the spatial variability through a variable rate application of inputs (Acevedo-Opazo et al., 2008; Arnó et al., 2009; Manfrini et al., 2009; Taylor et al., 2007; Tisseyre et al., 2007).

In fruit tree production, technology adoption is needed to make thinning and crop load mapping more efficient, to better manage pests, to detect water stress and to map yield performance of the trees (Ellis et al., 2010; Wulfsohn et al., 2012). All of these aspects have been investigated by scientists; this paper focuses on the possibility to monitor water stress and to schedule irrigation by continuous measurements of fruit trunk diameter (Conejero et al., 2007) or fruit growth monitoring (Corelli Grappadelli et al., 2012; Meron and Harnam, 2000). Other techniques, as using sensors to detect sap flow and consequently manage irrigation, have been evaluated buttheir complexity means the applicability of sap flow sensors is still quite far from commercial practice. Tools to monitor fruit and trunk diameter variation are commercially available and feature state-of-the-art technology, as it is even possible to build up wireless networks of these sensors, as is the case of the fruit gauges produced by Phytech Ltd. (http://www.phytech.com/), or precompetitive alternatives (Morandi et al., 2007). The use of fruit gauges is not yet widespread in fruit production, probably because a complete product comprising technology and a decision support system in order to guide farmer to manage irrigation does not exist, but one can expect a future development of a technology of this kind.

1.2 Intention to adopt Precision Agriculture Technology

After more or less 25 years from the inception of PA, it is important to examine what are the causes of its still unrealized goal: the worldwide diffusion of the PA concept in commercial agricultural practice. A recent research stated this quite aptly: “the fact that PA technology adoption remains relatively low, despite the positive attributes, creates a puzzle” (Aubert et al., 2012).

The causes of this deficiency are indicated as significant weaknesses in a SWOT Analysis proposed by Jochinke (2007):

1. difficulties in applying practical agronomic solutions to manage spatial variability,
2. difficulties in demonstrating measurable results in commercial situations,
3. need to demonstrate economic or environmental benefits,
4. poor standardisation of data presentation protocols (e.g., different colour schemes in the maps),
5. software and hardware platforms compatibility.

The first weakness could derive from the fact that PA may be defined as an “information intensive” practice, which could bring a data overload to the manager and therefore a practice that could create difficulties in the data elaboration phase (Stafford, 2000); this opinion was recently supported by the work of Lamb et al. (2008) which highlights how in many cases our ability to collect data has exceeded our ability of understanding and exploiting these data in a meaningful way. Furthermore, “producers don’t want to modify production practices to fit the technology, but they want that technologies should be tailored to fit within current production practices” (Hudson and Hite, 2003).

The second and third weaknesses could have different causes like the lack of rational procedures and strategies for determining the application requirements and the lack of scientifically validated evidence for the benefits. Lowenberg-DeBoer’s findings (1999) supported the hypothesis that precision farming can have risk benefits and Isik, Khanna and Winter-Nelson (2001) concluded their research saying that it is preferable to adopt PA technologies, like Variable Rate Application, only when the variability in soil quality and soil fertility is relatively high. In the following years, despite several environmental and economical benefits have been demonstrated (Bongiovanni and Lowenberg-Deboer, 2004; Pierce and Elliott, 2008), PA technologies have not been as widely adopted as the experts expected. Perhaps, this happened because of the fourth and fifth weaknesses, which stem from the fact that technologies were largely developed in areas other than agriculture and were then adapted to farming (Sassenrath et al., 2008).

Two approaches have been adopted by researchers in order to understand the causes of poor PA technology usage: *ex ante* and *ex post*. The most frequently used is the *ex post* methodology which analyses regressions between technology adoption and financial, socio-demographic and environmental variables. This methodology has revealed the drivers that had influenced the adoption, but only after the adoption occurred, in other words, after the farmer had already become a technology user. One of the most recent papers dealing with this topic was Tey and Brindal's review (2012). The selective method followed by the authors led them to identify 10 papers which described the motivational factors which had brought farmers to the decision of adopting PA. In this analysis they listed 34 significant factors divided in seven categories: 1) socio-economic factors, 2) agro-ecological factors, 3) institutional factors, 4) informational factors, 5) farmer perception, 6) behavioural factors and 7) technological factors. The review depicted the typical PA adopter: an older and more educated farmer; who has better soil quality and owns a large farm; who needs to improve the productivity of his agricultural practice due to development pressures; who prefers to hire consultants; who perceives PA as profitable and is already a self-confident user of computers.

Ex ante studies have a predictive value and are able to explain the factors affecting PA technology adoption, that is before a farmer makes his or her choice whether to purchase a PA technology or not. By *ex ante* studies it is possible to analyze the "perceived sphere" and the attitudinal aspects of human behavior, since potential users' perceptions are strictly connected to the intention to use a new technology. This topic is the core subject of the Technology Acceptance Model methodology (Davis and Venkatesh, 2004; Davis, 1989).

Within the agricultural context, the analysis of *ex ante* factors is useful to interpret the choices made by farmers when having to engage with new technologies and their adoption thereof (Bertschinger et al., 2012; Useche et al., 2012). To date, however, only 7 papers have been published, which followed the *ex ante* approach: three papers focus on willingness to pay (Hite et al., 2002; Hudson and Hite, 2003; Marra et al., 2010), while the other four are based on TAM (Adrian et al., 2005; Aubert et al., 2012; Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010).

1.3 The Theoretical Model (Technology Acceptance Model - TAM)

Technology Acceptance Model (TAM) is an *ex ante* theoretical model that is widely used to explain the process of adopting new technology (Davis, 1989; King and He, 2006). It is a behavioural model derived from the Theory of Planned Behaviour (Ajzen, 1991; Fishbein and Ajzen, 1975), that attempts to identify and test the relevance of certain factors in influencing a potential user's decision on how and when to utilise a new technology. Perceptual and attitudinal aspects of human behaviour are the core constructs of TAM methodology, with the focus of this approach directed towards the attitude to adopt or the intention to use technology.

The three constructs introduced by Davis (1989), that still are the core of TAM, are:

1. Perceived Usefulness (PU) defined as "the degree to which a person believes that using a particular system would enhance his or her job performance";
2. Perceived Ease of Use (PEU) defined as "the degree to which a person believes that using a particular system would be free of effort";
3. Usage (U).

Davis' research revealed the specific chain of causality PEU → PU → U. This important result demonstrated that a technology would be used more likely if it was perceived as useful and no amount of ease of use could compensate for a system that did not perform a useful function. The ease of use in fact can only increase the perception of usefulness but it doesn't lead to usage.

The theoretical framework of TAM has been improved adding previous constructs affecting PU and PEU (Karahanna et al., 1999; Venkatesh, 2000) or adding new constructs to fit a new technological context (Gefen and Straub, 2000; Kim et al., 2008; Lee and Chang, 2011; Li et al., 2008; Read et al., 2011) or verifying its reliability in the early phase of new technology development as before prototype creation (Davis and Venkatesh, 2004).

1.4 Technology Acceptance Model in Agriculture

Adrian et al. (2005) did not find confirmation of Davis' causality chain, in fact if PEU didn't affect Intention to adopt as in Davis, in Adrian et al. PEU didn't affect PU, and PU didn't affect directly Intention to adopt, but it acts instead through the Perceived Net Benefit. Here the authors give the demonstration that both Perceived Net Benefit and Attitudes toward technologies affect directly the Intention to Adopt PA technologies.

Folorunso and Ogunseye (2008) applied an enhanced Technology Acceptance Model including social factors and facilitating conditions. They found that age didn't negatively affect PU but only PEU, and the authors justified this result with the presence of researchers and extension workers between the respondents who probably feel more comfortable with technologies. The significance of social factors on intention to use implied that whether the subjects perceived peers' influence as important they would follow what others thought they should do. Facilitating factors instead positively affect the adoption because they create the conditions that influence the usage, like available professional support and accessibility to technologies.

Rezaei-Moghaddam and Salehi (2010) tested TAM with the addition of attitude of confidence, observability and trialability. Attitude of confidence was the confidence of a producer to learn and use precision agriculture technologies, observability was the extent to observe the results of an innovation, trialability was the possibility to test an innovation in a small area. The purpose was to predict the factors affecting intention to adoption of precision agriculture technologies. Trialability was defined as important only before usage because it represented the way farmers experimented with the technology, reducing risk and increasing the human/technology fitness. The consequence of trialability was a higher probability to adopt technology. Observability affected the farmers' perception of technologies because it represented the possibility to see their results. Producers who indicated confidence about using and learning precision agriculture technologies had greater propensity to adopt these technologies.

Recently Aubert, Schroeder, and Grimaudo (2012) combined the TAM theory with the Diffusion of Innovation (DOI) theory (Rogers, 1962) in order to investigate PA technology adoption among Canadian farmers. This research analyzed how attitudinal factors and other characteristics like operator's age and education and farm size affected the actual adoption of 6 PA technologies: GIS, GPS, yield monitors, variable rate application, crop scouting and remote sensing, guidance and navigation. The adoption rate was measured by a mail survey where respondents indicated which of these tools they were using. Differently from Adrian et al. and Davis (lit. cit.), PU and PEU both affected adoption, but the authors didn't find any relationship between them. This result indicated that these two constructs had worked together and independently in the decision whether or not to use a technology, but the authors proposed a further explanation of this finding: a heavy lack of compatibility had caused bad PEU and consequently a very poor contribution of PEU to PU. Compatibility among tools is in fact an important characteristic PA technologies should have since it was the most significant antecedent of PU and PEU. Availability of support, farmers' and employees' knowledge of PA, were the other factors affecting PEU, while PU was affected by, other than compatibility, information and relative advantage. Age and farm size didn't have any influence on adoption, while education level had a positive effect. A new construct introduced in this research was the Perceived Resources. This character was identified as an organizational attribute and it had the strongest influence on adoption.

This result appear sometimes contradictory and ambiguous, so the present paper aims to bring new insights to the examination of technology adoption in agriculture, focussing on TAM and a new technology, a decision support system comprising a wireless fruit gauges network, to manage irrigation in fruit production.

The originality of this research resides in these three points:

1. Ex ante. Adoption of PA technology is investigated by an *ex ante* approach (TAM) since in agriculture there is scarcity of *ex ante* studies.
2. Fruit. TAM is applied in the fruit production sector, never tested before.
3. Pre-prototype stage. TAM is applied to a new technology in a pre-prototype phase, not yet adopted by farmers. Predicting acceptance of a new technology is important to avoid failure and save money during the development phase. Working on a pre-prototype technology it is possible to capture the perception of usefulness of a target sample of

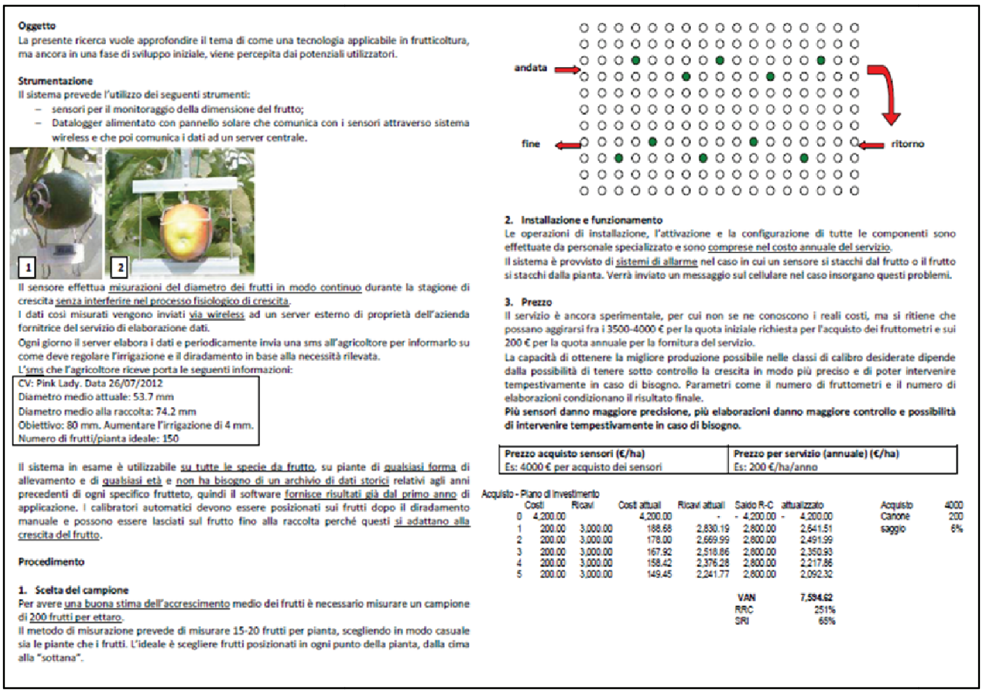
potential users who have received information about the technology but who did not have a direct usage experience (Davis and Venkatesh, 2004; Jain and Mandviwalla, 2006). This is important since the Perceived Usefulness is the strongest antecedent of adoption.

2. Method

2.1 Pre-prototype technology

This paper aims to give a contribution in understanding the factors affecting Precision Agriculture technology adoption, applying the Technology Acceptance Model with two new aspects added compared to previous researches: the fruit production context and the pre-prototype phase of the technology.

Figure 1. Mockup illustrating technology.



Oggetto
La presente ricerca vuole approfondire il tema di come una tecnologia applicabile in frutticoltura, ma ancora in una fase di sviluppo iniziale, viene percepita dai potenziali utilizzatori.

Strumentazione
Il sistema prevede l'utilizzo dei seguenti strumenti:
- sensori per il monitoraggio della dimensione del frutto;
- Datalogger alimentato con pannello solare che comunica con i sensori attraverso sistema wireless e che poi comunica i dati ad un server centrale.

Il sensore effettua misurazioni del diametro dei frutti in modo continuo durante la stagione di crescita senza interferire nel processo fisiologico di crescita.
I dati così misurati vengono inviati via wireless ad un server esterno di proprietà dell'azienda fornitrice del servizio di elaborazione dati.
Ogni giorno il server elabora i dati e periodicamente invia una sms all'agricoltore per informarlo su come deve regolare l'irrigazione e il diradamento in base alla necessità rilevata.
L'sms che l'agricoltore riceve porta le seguenti informazioni:

CV: Pink Lady. Data 26/07/2012
Diametro medio attuale: 53.7 mm
Diametro medio alla raccolta: 74.2 mm
Obiettivo: 80 mm. Aumentare l'irrigazione di 4 mm.
Numero di frutti/pianta ideale: 150

Il sistema in esame è utilizzabile su tutte le specie da frutto, su piante di qualsiasi forma di allevamento e di qualsiasi età e non ha bisogno di un archivio di dati storici relativi agli anni precedenti di ogni specifico frutteto, quindi il software fornisce risultati già dal primo anno di applicazione. I calibratori automatici devono essere posizionati sui frutti dopo il diradamento manuale e possono essere lasciati sul frutto fino alla raccolta perché questi si adattano alla crescita del frutto.

Procedimento

1. Scelta del campione
Per avere una buona stima dell'accrescimento medio dei frutti è necessario misurare un campione di 200 frutti per ettaro.
Il metodo di misurazione prevede di misurare 15-20 frutti per pianta, scegliendo in modo casuale sia le piante che i frutti. L'ideale è scegliere frutti posizionati in ogni punto della pianta, dalla cima alla "sottana".

2. Installazione e funzionamento
Le operazioni di installazione, l'attivazione e la configurazione di tutte le componenti sono effettuate da personale specializzato e sono comprese nel costo annuale del servizio.
Il sistema è provvisto di sistemi di allarme nel caso in cui un sensore si stacchi dal frutto o il frutto si stacchi dalla pianta. Verrà inviato un messaggio sul cellulare nel caso insorgano questi problemi.

3. Prezzo
Il servizio è ancora sperimentale, per cui non se ne conoscono i reali costi, ma si ritiene che possano aggirarsi fra i 3500-4000 € per la quota iniziale richiesta per l'acquisto dei fruttometri e sui 200 € per la quota annuale per la fornitura del servizio.
La capacità di ottenere la migliore produzione possibile nelle classi di calibro desiderate dipende dalla possibilità di tenere sotto controllo la crescita in modo più preciso e di poter intervenire tempestivamente in caso di bisogno. Parametri come il numero di fruttometri e il numero di elaborazioni condizionano il risultato finale.
Più sensori danno maggiore precisione, più elaborazioni danno maggiore controllo e possibilità di intervenire tempestivamente in caso di bisogno.

Prezzo acquisto sensori (€/ha)	Prezzo per servizio (annuale) (€/ha)
Es: 4000 € per acquisto dei sensori	Es: 200 €/ha/anno

Acquisto - Piano di investimento

	Costi	Ricavi	Costi attual	Ricavi attual	Saldo R-C	attualizzato		
0	4,200.00		4,200.00	-	- 4,200.00	- 4,200.00	Acquisto	4000
1	200.00	3,000.00	188.68	2,830.19	2,800.00	2,641.51	Canone	200
2	200.00	3,000.00	178.00	2,669.99	2,800.00	2,491.99	saggio	6%
3	200.00	3,000.00	167.92	2,518.86	2,800.00	2,350.93		
4	200.00	3,000.00	158.42	2,376.28	2,800.00	2,217.86		
5	200.00	3,000.00	149.45	2,241.77	2,800.00	2,092.32		
					VAN	7,594.62		
					RRC	251%		
					SRI	65%		

The Technology Acceptance Model is more useful if it is referred to a specific technology rather than to a not-well-defined series of available technologies. Besides, in this study we work on a not-yet-existing technology in order to obtain a valuable guidance in the very early stage of development of a new technology. We built up a simple mockup representing a wireless network of fruit gauges capable to manage irrigation autonomously. Mockup was a simple text, as reported in Davis and Venkatesh (2004), sufficient enough to detect if "a potential user can form accurate judgements regarding a new system".

The mockup illustrated picture of fruit gauges, functionality description of the wireless system and price (Figure 1).

2.2 Items

A list of 19 items was created, drawing on previous researches using TAM in agriculture but especially in other sectors, such that Technology Acceptance Model was often tested on Decision Support Systems (DSS) and Information and Communications Technologies (ICT), rather than Precision Agriculture technologies, therefore it was logical to borrow from other sectors to find items. The survey developed for this study aims to measure constructs of Perceived Usefulness, Perceived Ease of Use, Perceived Cost, Support, and Usage Intention. The list of items used in this survey is represented in Table 1. These items then were adjusted to Precision Agriculture.

Perceived Usefulness items were taken from Davis (1989) and Adrian (2005). The Davis item "Control over work" was inspiring because the technology reported in this paper makes possible to control and monitor fruit growth, therefore it could represent a way to increase just the "Control over work" in the fruit production sector, where such control is known to be very difficult to realize. This item was developed and modified in order to fit fruit growers' risk aversion, i.e., the risk to produce excessive amounts of small size fruit and to not manage irrigation as best as possible (Ellis et al., 2010) , which leads to the fear to have an uncertain economic outcome (Hardaker, 2000; Lowenberg-DeBoer, 1999) , a concern common to all farmers, fruit growers included.

Perceived Ease of Use items were taken from Davis (1989), Davis and Venkatesh (2004) and Adrian et al. (2005), while Support items were taken from Karahanna and Straub (1999) and Venkatesh (2000).

Perceived Cost items were created referring to PA literature and technology adoption papers where the willingness to pay and the price perception have been evaluated (Hudson and Hite, 2003; Marra et al., 2010; Varki and Colgate, 2001). In this construct even the time was considered that a farmer should spend to learn to use the PA technology (Reichardt and Jürgens, 2009; Walton et al., 2008).

The respondents were asked to answer to every item assigning a vote on a Likert scale from 1 to 7, where 1 corresponded to "totally disagree" and 7 was "totally agree". In order to avoid bias the items were randomized to create four different questionnaires where items were sorted differently.

Table 1. List of items.

Perceived Usefulness	
PU1	L'utilizzo dello strumento permette di ottenere un profitto costante e sicuro ogni anno.
PU2	L'utilizzo dello strumento riduce significativamente i rischi di gestione del frutteto.
PU3	L'utilizzo dello strumento fornisce informazioni fondamentali per lo staff commerciale.
PU4	Questo strumento è estremamente utile per svolgere bene il mio lavoro.
Perceived Ease of Use	
PEU1	L'utilizzo dello strumento è scomodo.
PEU2	L'utilizzo dello strumento è spiegato in modo chiaro e comprensibile.
PEU3	Imparare ad usare lo strumento è facile.
PEU4	L'utilizzo dello strumento è facile.
Perceived Cost	
PC1	L'utilizzo dello strumento richiede un impiego di ore di lavoro molto alto.
PC2	L'utilizzo dello strumento non si concilia bene con le altre cose da fare.
PC3	La spesa monetaria da sostenere per utilizzare lo strumento è troppo alta.
Support	
SUP1	Io ritengo fondamentale poter ricevere aiuto e consulenza dirette quando c'e n'è bisogno.
SUP2	Io ritengo importante essere addestrato ad usare lo strumento.
SUP3	Penso che non avrò bisogno di aiuto per imparare ad usare lo strumento.
SUP4	La presenza nella mia zona di un tecnico a cui chiedere aiuto in caso di bisogno mi permetterebbe di sfruttare a pieno le potenzialità dello strumento.
Usage Intention	
UI1	Mi piacerebbe molto provare ad usare lo strumento.
UI2	Io penso che in futuro userò regolarmente questo tipo di strumenti.
UI3	Penso che consiglierò l'utilizzo dello strumento ai miei colleghi/tecnici/superiori.
UI4	I benefici ottenuti da questo strumento sono maggiori dei costi.

Statistical analysis was carried out with the programs IBM SPSS Statistics 17.0 and IBM SPSS AMOS Version 21. The first step was an Exploratory Factor Analysis (EFA) since it is useful to model specification prior to cross validation with a Confirmatory Factor Analysis (CFA). EFA could be designed for the situation where links between observed and the latent variables are unknown or uncertain, in order to detect which items were explained by the same latent factors (Gerbing and Hamilton, 1996).

As a second step, a Confirmatory Factor Analysis (CFA) was performed in order to depict the links between the latent variables and their observed measures, and the links among the latent variables themselves.

2.3 Participants

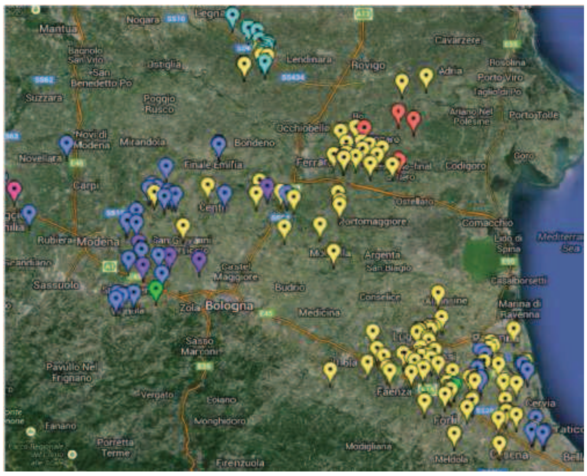
Precision Agriculture management is not a common practice in Italy and especially in the fruit production sector, so many fruit growers are not aware of PA. The target participants for this survey were fruit growers of Emilia Romagna and Veneto regions, both very important in fruit production. The sample frame was composed by fruit growers' names provided by cooperatives in the provinces of: (from southern to northern) Forlì-Cesena, Ravenna, Bologna, Modena, Ferrara, Rovigo, Verona. Every cooperative contributed with a different number of contacts depending on internal policy so that a final list of 174 fruit growers had been created. Each fruit grower of this list was contacted by phone during the winter 2012/2013. The first call was necessary to present the research project and then, if the farmer was helpful, to set an appointment. The number of farmer who agreed to participate to the survey was 114 and they were interviewed in a face-to-face meeting.

Every interview started providing information about the Wireless Fruit Gauges Network to the farmer by reading the mockup, and then he was asked to answer the questions. 114 fruit growers were surveyed, with a rate of response of 65.5%, in the North of Italy. The face-to-face interview allowed to obtain a 100% rate of responding, for a total of 114 usable surveys.

3 Results

The respondents were from the provinces of Forlì-Cesena, Ravenna, Bologna, Ferrara and Modena, in the Emilia Romagna region, and the Rovigo and Verona provinces, in the Veneto region (Figure 2). The provinces of the two northern regions are part of an important fruit production area in the Po valley where it is possible to find almost all the temperate fruit species cultivated in Italy (stone fruit, pome fruit, kiwifruit, persimmon).

Figure 2. Geographical distribution of farmers. Yellow points indicate all the respondents.



The mean age of the respondents was 49 years old, and the median is 50, in fact the 51.8% were older than 50 years. Figure 3 shows the distribution of different classes of age. The average farm acreage dedicated to fruit production is 9.47 hectares, with the smallest farm having only 1.4 ha and the largest one having 42.7 ha of fruit orchards. Figure 4 shows the 6 educational levels which have been detected: primary school (primary), junior high school (med, 3 years after primary school), senior high school (dip, 2 or 3 years after junior high school), or its alternative high school (high, 5 years after junior high school), graduate degree (3 or 5 years after high school) and the postgraduate academic degree (PhD). The average level of education is 8th Grade. The two main classes representing the educational level were just middle (8th Grade) and high (13th grade) school, both including the 38.6% of the participants.

Figure 3. Age distribution.

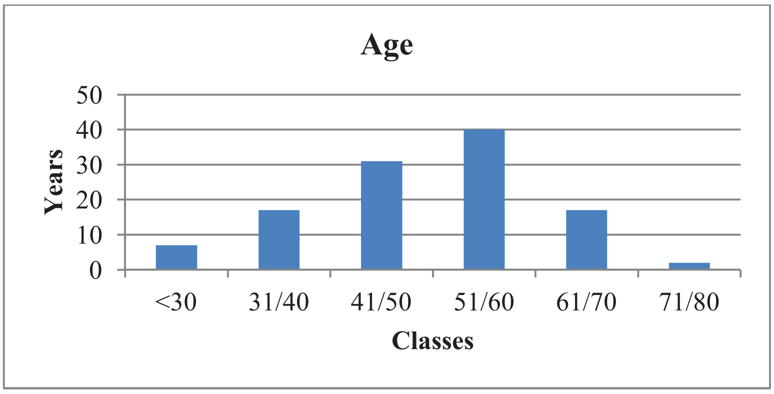
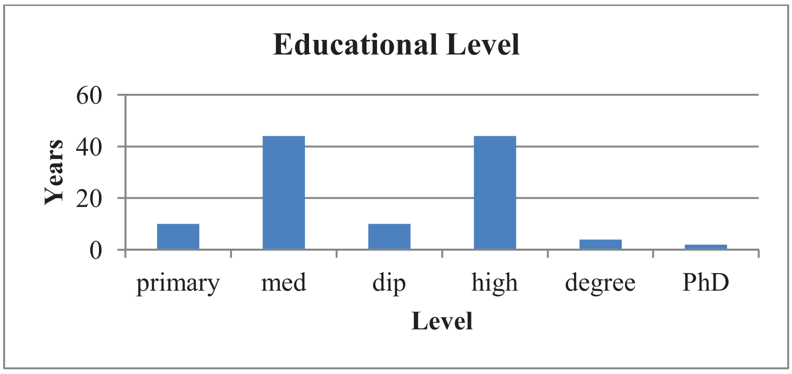


Figure 4. Educational Level distribution.



3.1 Exploratory Factor Analysis (EFA)

An Exploratory Factor Analysis (EFA) was conducted with IBM SPSS Statistics 17.0 software in order to test relationships of each variable to constructs. Basically EFA technique allows to search for structure among variables by defining factors in terms of set of variables. EFA explores data and provides information about how many factors are needed to best represent the data. In this case EFA was conducted to confirm how many factors really existed and which variables belonged with which constructs. This offers the possibility to reestimate the model (Byrne, 2009).

A Maximum Likelihood extraction with eigenvalue greater than 1 was imposed and a Promax rotation method has been applied because this is an oblique rotation that can better represent factor intercorrelation (Ford et al., 1986). The pattern matrix indicated that items PU4, PC3, SUP2, and SUP4, had extracted values lower than 0.3 (data not shown), therefore these items were dropped.

Table 2. KMO and Bartlett's Test.

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		0,739
Bartlett's Test of Sphericity	Approx. Chi-Square	458,135
	df	105
	Sig.	,000

Furthermore PC1 and PC2 were loaded on the PEU factor, since these items addressed the difficulty to use a technology, in fact they asked farmers to consider the time spent to learn to use a technology (PC1) and if the technology would fit well in the current practice. After establishing that PC1 and PC2 loaded on PEU they were renamed PEU5 and PEU6 respectively (Byrne, 2009). All the other items loaded appropriately on their expected constructs.

Table 3. Total Variance Explained.

Factor	Initial Eigenvalues			Extraction Sums of Squared Loadings			Rotation Sums of Squared Loadings[a]
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %	Total
1	4,002	26,678	26,678	1,502	10,015	10,015	2,690
2	2,006	13,372	40,050	3,128	20,854	30,869	2,616
3	1,615	10,764	50,815	1,300	8,667	39,537	2,248
4	1,204	8,029	58,843	1,095	7,297	46,834	1,506

Table 2 represents the two sampling adequacy tests, KMO and Bartlett. The KMO index was good because it was above 0.7 while the Bartlett's test of sphericity was significant (< 0.05) indicating that the matrix is not an identity matrix and that the variables do relate to one another enough to run a meaningful EFA (Bartlett, 1937; Frohlich and Westbrook, 2001; Kaiser, 1970). The analysis extracted 4 factors which explained almost 47% of the total variance (Table 3).

Factor loadings, presented in Table 4, were all above 0.3 or 0.4, values indicated as cutoffs value in social science researches (Adrian et al., 2005; Gefen and Straub, 2000).

Overall, the factor analysis shows a simple loading pattern with high convergent and discriminant validity. The factor correlation matrix (Table 5) shows that the factors are distinct and uncorrelated since no correlation values exceeded 0.7. Reliability estimates were conducted calculating Cronbach's Alpha (Table 4). The first three constructs (in order: PEU, UI and PU) presented values of Cronbach's Alpha, .708, .740, .720 respectively, which are good, as they overcome the threshold level of .70, thus entering in the range of values reported in the literature (King and He, 2006; Nunnally, 1978). The last factor (Support) had only a Cronbach's Alpha of .671, this could be related to the low number of items (only 2) and to the small sample size. Nonetheless, this value could be considered good, since Cronbach's Alpha values lower than the recommended .70 had been already reported in prior researches of TAM in agriculture (Aubert et al., 2012) and in social science (Kim et al., 2008).

Table 4. Pattern Matrix.

	Factor			
	1	2	3	4
Cronbach's Alpha	**.708**	**.740**	**.720**	**.671**
PC1 (PEU5)	.668			
PEU4	.634			
PC2 (PEU6)	.618			
PEU3	.572			
PEU2	.548			
PEU1	.520			
UI4		.798		
UI2		.684		
UI3		.594		
UI1		.435		
PU1			.908	
PU2			.617	
PU3			.538	
SUP2				1.000
SUP4				.542

Table 5. Factor Correlation Matrix

Factor	1	2	3	4
1	1,000			
2	,319	1,000		
3	,367	,410	1,000	
4	,050	,097	,234	1,000

3.2 Confirmatory Factor Analysis (CFA)

A Confirmatory Factor Analysis was conducted in order to evaluate the

Measurement Model, the preliminary test of TAM. CFA is also necessary to confirm theory of TAM applied in agriculture, specifically in fruit production, on a pre-prototype technology.

Table 6. Regression Weights.

			Estimate	S.E.	C.R.	P	Label
UI1	←	UI	.715	.130	5.513	***	
UI2	←	UI	.854	.148	5.755	***	
UI3	←	UI	.810	.154	5.248	***	
UI4	←	UI	1.000				
PU1	←	PU	1.000				
PU2	←	PU	.960	.183	5.247	***	
PU3	←	PU	.679	.135	5.026	***	
PEU1	←	PEU	.908	.202	4.500	***	
PEU2	←	PEU	.430	.092	4.679	***	
PEU3	←	PEU	.469	.110	4.277	***	
PEU4	←	PEU	.526	.105	4.987	***	
PEU5	←	PEU	.872	.232	3.766	***	
PEU6	←	PEU	1.000				
SUP2	←	SUP	.880	.401	2.194	.028	
SUP4	←	SUP	1.000				

In a CFA, differently from EFA, we specified both numbers of factors and which factors each variable will load on. In this case items have been assigned to a specific factor after an EFA, and this was useful to detect variables which loaded on a non-expected factor and so re-estimate the model. Now CFA is applied to test how well theoretical specification of the factors matches real data.

Table 7. Construct Validity.

	CR	**AVE**	**PEU**	**UI**	**PU**	**SUP**
PEU	0.764	0.355	0.596			
UI	0.747	0.427	0.506	0.653		
PU	0.731	0.480	0.406	0.453	0.693	
SUP	0.729	0.579	0.065	0.305	0.150	0.761

The first step in a CFA is validating the measurement model and checking the construct validity. Regression weights, in Table 6, revealed good factor loadings but PEU2 and PEU3 were lower than .5, this could create some concerns since the average estimates (AVE column in Table 7) revealed that PEU, presenting the lowest value, is the most problematic (AVE < .5). It is possible to try to increase AVE by looking to the lowest factor loadings in Table 6 and deleting them and then recalculating the new factor loadings. This recalculation was done but no improvement was obtained, therefore results are not presented here. Anyway, for discriminant validity, diagonal elements should be larger than off-diagonal elements and, as shown in Table 7, the value estimated reflected this recommendation (Adrian et al., 2005). Furthermore, Table 7 confirms a good Construct Reliability (CR), since all values are greater than .7 (Fornell and Larcker, 1981; MacKenzie et al., 2011).

Standardized regression weights (Table 8) are all greater than .5, the cutoff value, except for PEU5 that had .462, while covariances are all lower than .7 (Table 9) indicating that no covariance relation existed among factors (Byrne, 2009).

Table 8. Standardized Regression Weights.

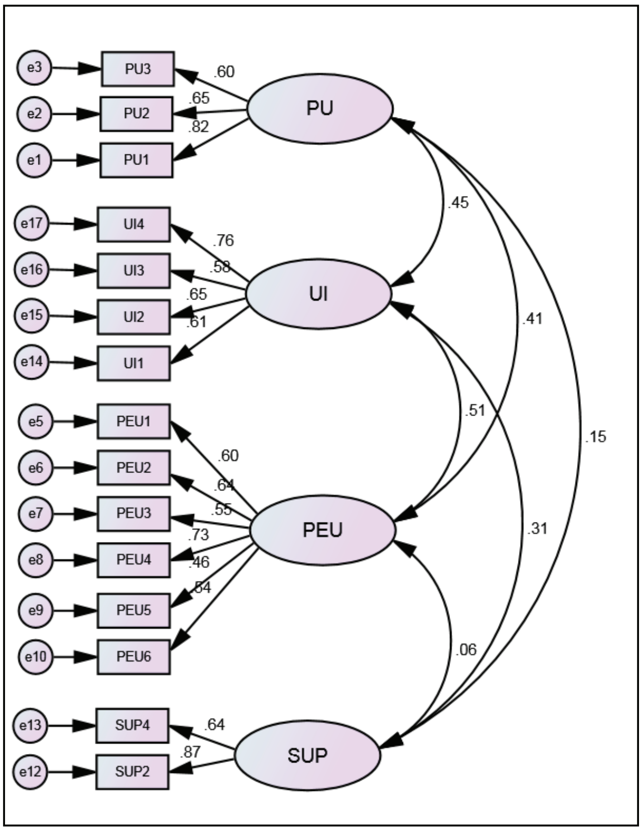
	Estimate
UI1 ← UI	.613
UI2 ← UI	.647
UI3 ← UI	.579
UI4 ← UI	.760
PU1 ← PU	.815
PU2 ← PU	.647
PU3 ← PU	.597
PEU1 ← PEU	.601
PEU2 ← PEU	.643
PEU3 ← PEU	.555
PEU4 ← PEU	.734
PEU5 ← PEU	.462
PEU6 ← PEU	.543
SUP2 ← SUP	.867
SUP4 ← SUP	.638

Table 9. Covariances.

	Estimate
UI ↔ PU	.522
PU ↔ SUP	.123
PU ↔ PEU	.394
UI ↔ SUP	.265
UI ↔ PEU	.519
PEU ↔ SUP	.047

The relationships between the latent construct and the respective measured variables are the factor loadings and are represented by arrows from the construct to the measured variable. This kind of drawing means that the latent construct determines the variable. Correlations among constructs are represented by two-headed curve arrows, and finally the error terms indicate the extent to which each latent factor does not explain the measured variable (Byrne, 2009). It is possible to see the lowest factor loadings of variables PEU3 and PEU5, and the two greater covariance estimates for PU-UI (0.45) and PEU-UI (0.51) correlations. These results however confirmed that factors are distinct and uncorrelated since no correlation values exceeded 0.7.

Figure 5. CFA - Path Diagram – CFA with Standardized Regression Weights.



The fit indexes of CFA are reported in Table 10. The absolute fit indexes considered are the Normed Chi-Square (CMIN/DF), the Goodness of Fit Index (GFI) and Root Mean Square Residual (RMSEA). The Normed Chi-Square is the chi-square value divided by the degrees of freedom (95.091/84 = 1.132) and it is good since a very good score should be under the cutoff value of 2.0, while scores between 2.0 and 5.0 are acceptable. Goodness-of-fit-index (GFI > 0.9 recommended) and Root Mean Square Residual (RMSEA < 0.08

recommended and insignificant p-value) are both good since they are respectively 0.902 and 0.034 (with p-value = .777). Other indexes are the incremental fit indexes and the parsimony fit indexes. Of the first group, Comparative Fit Index (CFI > 0.9 recommended) and Tucker-Lewis Index (TLI > 0.9 recommended) exceeded the recommended levels. Of parsimony fit indexes, the Parsimony Normed Fit Index (PNFI, 0.6 < X > 0.9 recommended) was selected and it revealed a good score since it was 0.643.

Table 10. Goodness of Fit Measures.

	Recommended Values	Measurement Model
Chi-square	> 0.05	Chi-square = 95.091 Degrees of freedom = 84 Probability level = .192
CMIN/DF	1.0 – 5.0	1.132
GFI	> 0.90	0.902
RMSEA	< 0.08	0.034
CFI	> 0.90	0.971
TLI	> 0.90	0.963
PNFI	0.6 < X < 0.9	0.643

3.3 Structural Equation Model (SEM)

In building up a Structural Equation Model (SEM) the first thing to do is defining Endogenous and Exogenous constructs. An Endogenous construct is a latent multi-item construct equivalent to a dependent variable, in a path diagram one or more arrows lead into the Endogenous construct. An Exogenous construct is a latent multi-item construct equivalent to independent variable and it is determined by factors outside the model.

Relationships between Endogenous and Exogenous constructs are the structural relationships of the model and had to be imposed based on theoretical assumptions.

3.3.1 Hypothesis development

Research has shown the importance of predicting potential users' attitude towards information technologies before a usage experience occurred, in order to predict behavioural intention and actual adoption of technologies like e-mail, software, internet, web sites, word processing, database, etc… (Gefen and Straub, 2000; Karahanna et al., 1999; Read et al., 2011).

Technology Acceptance Model (TAM) is the theoretical framework that makes possible to predict which human perceptions influence the choice whether to use a technology or not. The core of TAM are two constructs, Perceived Usefulness (PU) and Perceived Ease of Use (PEU), that affect the intention to adopt and the actual use of a new technology (Davis, 1989). Besides these two seminal constructs, other constructs have been added by scientists searching for antecedent constructs and variables affecting the two principal ones or for other variables affecting adoption.

The present research focuses on four constructs (Figure 6): Usage Intention, Perceived Usefulness and Perceived Ease of Use, and Support (as the importance assigned to support provided to farmers in order to make them able to use a new technology).

3.3.2 Perceived Usefulness

Perceived Usefulness (PU) was defined by Davis (1989) as "the degree to which a person believes that using a particular system would enhance his or her job performance". His research demonstrated that PU directly affected the Usage intention (U) and that PU mediated the effect of PEU on U. This finding was not confirmed in Adrian et al. (2005), who did not find any correlation between PU and Intention to Adopt (IA) but the effect of PU on IA was mediated by the perception of benefit (Perceived Net Benefit). However, other studies conducted on Precision Agriculture technologies confirmed that PU had a significant effect on Attitude to Adopt (Aubert et al., 2012; Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010).

A further "useful" aspect is the risk management. PA aims to reduce or manage field variability, in order to help farmers to yield a constant production and to ensure higher incomes. This means to reduce the probability of a negative outcome and the uncertainty of outcomes (Batte and Arnholt, 2003; Hardaker, 2000).

In this research PU was evaluated by items used to measure productivity, risk reduction, improvement of performance over existing practice, effectiveness. The hypothesis is that a farmer who perceives a new technology as useful is more likely to adopt the technology as reported below in Hypothesis 1 (H1).

H1. Perceived Usefulness positively affects Usage Intention.

3.3.3 Perceived Ease of Use

Perceived Ease of Use (PEU) was defined as "the degree to which a person believes that using a particular system would be free of effort" and in Davis' research we found that PEU can influence the use of technology only through PU. It means that the ease of use can increase the perception of usefulness but it doesn't lead to usage directly.

On the other hand, in PA sector, PEU was found to be directly influencing Attitude (Aubert et al., 2012; Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010), and only in one case PEU affected PU other than attitude to use (Rezaei-Moghaddam and Salehi, 2010).

In this paper, respecting this findings, the hypothesis is that PEU can have a significant effect on both PU and usage intention (UI).

H2a. Perceived Ease of Use positively affects Perceived Usefulness
H2b. Perceived Ease of Use positively affects Usage Intention

3.3.4 Support

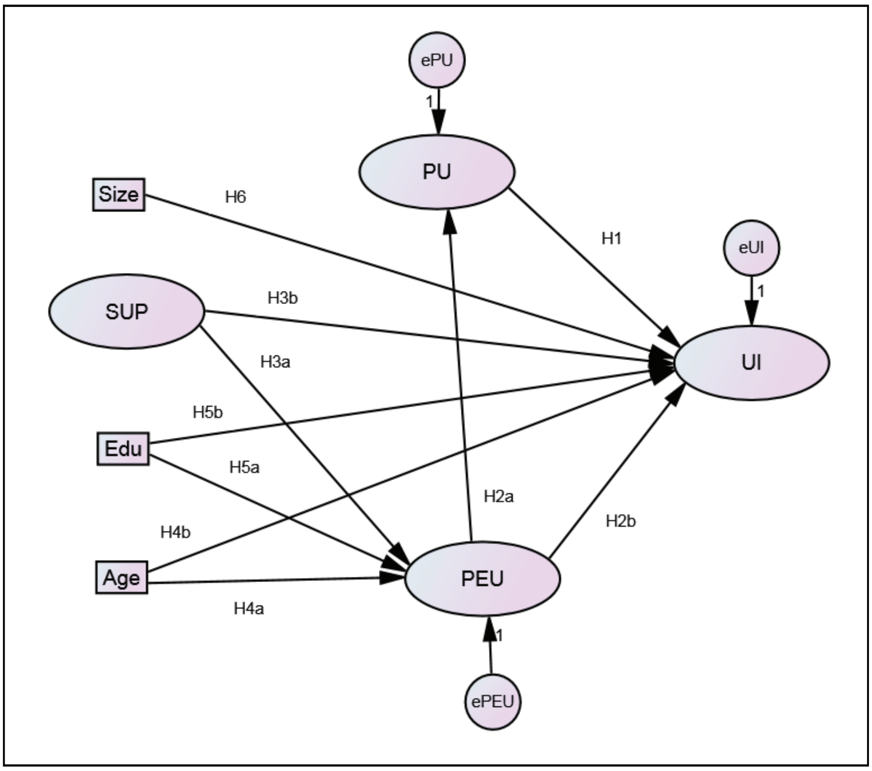
This construct embodies the importance assigned by farmers to support service. PA literature showed that farmers need support and this must be provided by sellers, experts and Extension Services agents in order to make farmers able to use PA technologies (Folorunso and Ogunseye, 2008; Robertson et al., 2012). A farmer wants to rely on the presence of PA consultants close to her or him, on available support service personnel in the case of necessity and on the possibility to learn to use a technology and then interpret data correctly (Daberkow and McBride, 1998; Larson et al., 2008; Robertson et al., 2012). Scientists have demonstrated that the presence of experts about PA technology is required by farmers to initiate a learning process, enabling potential users to become more aware and confident about PA tools, and thus promoting the perception of an "easy to use" technology (Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010).

Venkatesh (2000) showed that both the perception of external and internal control had influenced Perceived Ease of Use, two antecedent constructs related to availability of consultant support, but, Karahanna and Straub (1999) found that an end-user's perception of how a technology is easy-to-use was not affected by the support provided. Therefore, the relation between Support and PEU is still unclear, for this reason this research investigated the possibility that Support could influence Usage Intention through two ways: mediated by

PEU and also directly. Since in previous researches the relation between Support and PU had never been investigated, even in this research this possible path was excluded.

H3a. The importance assigned to Support positively affects PEU
H3b. The importance assigned to Support positively affects UI

Figure 6. Structural Equation Model.



3.3.5 Other variables

Precision Agriculture literature showed that some demographic factors could affect adoption. In this paper we consider the variables Age, Education and Size since they were the most cited in prior researches. Age has been included mainly in *ex post* papers, but no well defined relationship between age and adoption has been found. In some cases adoption was related to younger age because younger farmers had larger working horizons (D'Antoni et al., 2012; Kutter et al., 2011; Larson et al., 2008; Walton et al., 2008), while in some cases age is positively connected to PA usage, therefore indicating that older farmers (over 50 years) are more likely to adopt new technologies

(Torbett et al., 2007).

In *ex ante* literature Age negatively affected PEU (Folorunso and Ogunseye, 2008) while Aubert et al. (2012) did not find any correlation between Age and adoption, therefore in this study we would like to investigate some new explanation on how Age could influence Perceived Ease of Use and Usage Intention. It is reasonable that an older farmer would find more difficult to learn to use new technologies and therefore would be less willing to use technology; for these reasons the hypotheses formulated is that Age negatively affects both PEU and UI.

H4a. Farmer's age negatively affects PEU
H4b. Farmer's age negatively affects UI

In most research conducted on Precision Agriculture technologies, adoption had often been associated to a higher educational level. At the same time the larger the farm, the higher the intention to adopt PA technologies. (Adrian et al., 2005; Tey and Brindal, 2012). In this paper Education was considered as the number of the years of school attendance, and Size was represented only by the acreage cultivated with fruit trees.

Hypotheses were that a more educated farmer could perceive a technology as easier to use than a less educated one, and that he would be more willing to use PA technology.

H5a. Farmer's education positively affects PEU
H5b. Farmer's education positively affects UI

Finally a fruit grower who managed a bigger fruit production area should be more inclined to use technology than a fruit grower of a smaller farm.

H6. Farm size positively affects UI

3.4 Model estimation

The analysis of Structural Equation Model was conducted with AMOS. Discriminant validity, the variance extracted and the Cronbach's Alpha of each construct has been already explained with the EFA (Tables 2 to 7). Goodness of fit indexes are reported in Table 11. The Normed Chi-Square (CMIN/DF =

1.266), RMSEA (0.049, p-value = .527) and CFI (0.915) are all within acceptable levels, while GFI (0.867), TLI (0.899) and PNFI (0.592) are close to the cutoff value indicating a good, but not perfect, fitness between the proposed model and data.

Table 11. Goodness of Fit Measures.

	Recommended Values	Structural Model
Chi-square	> 0.05	Chi-square = 162.039 Degrees of freedom = 128 Probability level = .023
CMIN/DF	1.0 – 5.0	1.266
GFI	> 0.90	0.867
RMSEA	< 0.08	0.049
CFI	> 0.90	0.915
TLI	> 0.90	0.899
PNFI	0.6 < X < 0.9	0.592

3.5 Hypothesis testing

The model explained 46.8% of the variance as already shown in Table 3. Standardized coefficients and *p*-level of all the hypotheses tested are summarized in Table 12 and drawn in Figure 7. Hypothesis 1 was confirmed as Perceived Usefulness directly affected Usage Intention of Precision Fruit growth technology. (H1 = .268, p = .043).

Perceived Ease of Use influenced the intention to use technology (UI) in two ways: its effect was mediated by Perceived Usefulness (H2a = .452, p = .003) but it also had a direct and strong effect on UI (H2b = .472, p = .005). This result was surprising because the relationship PEU-UI had a greater standardized coefficient than PU-UI, meaning that in this survey PEU had a stronger effect, than PU, in influencing UI.

The importance assigned to Support did not influence the perception of ease of use (H3a = .046, p = .725) but Support could directly affect UI (H3b = .327, p = .034).

The hypothesis 4 (a, b), 5 (a, b) and 6 were not supported. Age did not affect either PEU (H4a = -.012, p = .170) or UI (H4b = -.009, p = .342); Education was not significant in influencing either PEU (H5a = .007, p = .817) or UI (H5b = -.057, p = .060) even if this last path was close to be relevant as reported by many prior researches. Finally, farm Size, in terms of fruit production area, did not affect UI (H6 = .005, p = .735).

Table 12. Standardized Regression Weights. ("*" indicates significant paths).

Hypothesis	Estimate	SE	p-level
PU → UI H1. Perceived Usefulness positively affects Usage Intention.	.268	.132	.043*
PEU → PU H2a. Perceived Ease of Use positively affects Perceived Usefulness	.452	.155	.003*
PEU → UI H2b. Perceived Ease of Use positively affects Usage Intention	.472	.168	.005*
SUP → PEU H3a. The importance assigned to Support positively affects PEU	.046	.132	.725
SUP → UI H3b. The importance assigned to Support positively affects UI	.327	.154	.034*
Age → PEU H4a. Farmer's age negatively affects PEU	-.012	.009	.170
Age → UI H4b. Farmer's age negatively affects UI	-.009	.009	.342
Edu → PEU H5a. Farmer's education positively affects PEU	.007	.028	.817
Edu → UI H5b. Farmer's education positively affects UI	-.057	.030	.060
Size → UI H6. Farmer's size positively affects UI	.005	.014	.735

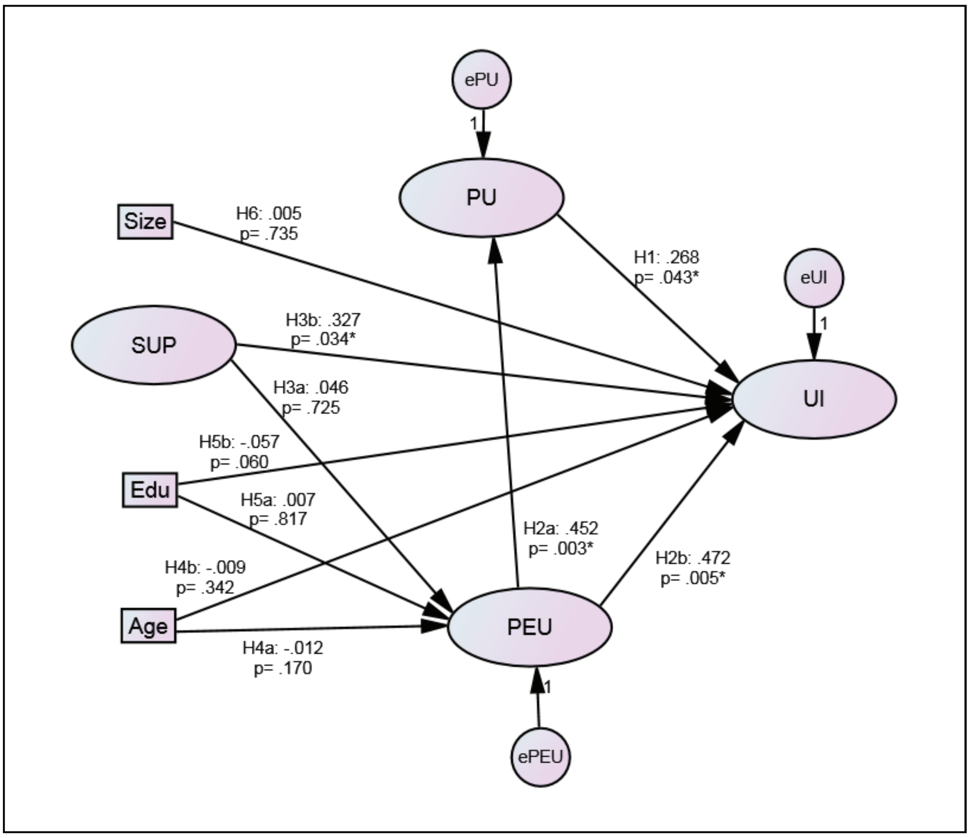
The Sobel test was calculated using this formula:

$$z = \frac{ab}{\sqrt{(b^2 SE_a^2) + (a^2 SE_b^2)}}$$

Where "a" (=.452) is the regression coefficient for the relationship between PEU and the mediator, in this case PU, "b" (=.268) is the regression coefficient for the relationship between PU and UI , "SE_a" (=.155) is the standard error of the relationship between PEU and PU, and "SE_b" (=.132) is the standard error of the relationship between PU and UI. The Sobel test was conducted to see if the indirect path from PEU to UI (through PU) is statistically significantly different from zero. The test statistic is equal to

1.6662331, with standard error 0.07270051. The statistical significance is equal to 0.095667. Assuming we had set our alpha at .05, technically, we would not reject the null hypothesis of no mediation. We would conclude that the relationship between Perceived Ease of Use and Usage Intention is mediated by Perceived Usefulness (Sobel, 1982).

Figure 7. Structural Equation Model indicating path results and *p*-values associated with each standardized regression weight.



Results indicated that fruit growers could have the intention to adopt a new technology if it was perceived as useful and easy to use at the same time. This finding was a confirmation of what has been already reported by prior *ex ante* researches on a pre-prototype technology (Davis and Venkatesh, 2004) and on TAM in agriculture, so that a new Precision Agriculture technology should be as useful as easy to use in order to be adopted (Aubert et al., 2012; Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010). Furthermore, this research showed that if a technology was perceived as easy to use, this could make the technology perceived also as more useful, since PEU had also a mediated effect on UI through PU. This path agreed with findings of the seminal TAM research conducted by Davis (1989).

In this survey, Support did not affect PEU as already demonstrated by Karahanna and Straub (1999) but differently from Aubert et al. (2012) who examined the Quality of Support. However in this research Support showed a direct effect on UI, demonstrating the importance of training and of the availability of experts close to the end users' technology. This result agreed with Folorunso and Ogunseye's (2008), reporting that Facilitating Factors positively affected the adoption because they created the conditions that influenced the usage, like available and professional support and accessibility to technologies.

Here we found neither direct nor indirect influence of socio-demographic variables (Age and Education) and farm Size on intention to use a Precision Agriculture technology. Previous *ex ante* research showed different patterns about these variables. A summary could be presented here in order to face with anyone of each: Age negatively affected the perception of ease of use (Folorunso and Ogunseye, 2008) and did not have any direct influence on adoption (Aubert et al., 2012); Education had been always positively related to adoption (Adrian et al., 2005; Aubert et al., 2012) while farm size positively affected technology adoption in Adrian et al. (2005) but did not in Aubert et al. (2012).

4. Discussion

Precision Agriculture technology adoption had been mostly studied by an *ex post* point of view, where the user's profile had been depicted and the use of technology had been related to some socio-demographic variables (Tey and Brindal, 2012). Less effort has been spent in analyzing PA technology adoption by an *ex ante* approach, borrowing by the information technology research theory. Technology Acceptance Model (TAM) is a research methodology that has been widely used in different fields, and so it has been applied in this study because it had already demonstrated to be a powerful tool, able to predict the behavior of potential users and the acceptance of a new technology (King and He, 2006).

An *ex ante* research, as TAM, could be useful in PA context because it could contribute to explain the low adoption rate still reported by researchers, and finally to help scientists and stakeholders to understand farmers' perception and attitude towards these PA tools, not yet widely adopted in the current agricultural practice.

This study aims to give a contribution in examining farmers' perceptions of PA technology and adding some remarks about the possibility to predict the acceptance of a new PA technology in the early stages of project development (Davis and Venkatesh, 2004). This early analysis could provide valuable information to technology developers in order to avoid errors and wasting time and money in an unsuitable technology.

This research found that the perception of a useful technology is as important as the perception of an easy to use technology in affecting the intention to adopt. In this case, PEU had even a stronger effect on UI than PU. This could represent a specific characteristic of Precision Agriculture context since the combination of PU and PEU influence on adoption has been already detected in 3 of 4 "PA-TAM" previous researches (Aubert et al., 2012; Folorunso and Ogunseye, 2008; Rezaei-Moghaddam and Salehi, 2010). This research confirmed that, differently from ICT es studies, in Precision Agriculture usefulness does not represent the main factor affecting the attitude to adopt (King and He, 2006), but the ease of use exerts a strong effect on adoption, both directly and mediated by PU.

This capacity of PEU in influencing adoption by two paths is an important issue that is worth considering. The perception of ease of use can influence the potential user' behavior towards the decision to adopt a technology, but at the same time PEU enforced the perception of usefulness by making the technology perceived as more useful. In Precision Agriculture usefulness and ease of use represent two requisites that must exist together in order to make the farmer become an adopter.

Furthermore, Support is another important factor that must be considered. Support influenced directly the intention to adopt a technology and its path coefficient was as great as PU's. This means that the presence of PA technology consultancy could make the difference between adoption and non-adoption. Without Support, even a useful and an easy to use technology could be barely used.

In the information and communication technology sector, Davis (1989) and subsequent researchers (King and He, 2006) confirmed the higher strength of usefulness, so they concluded that "no amount of ease of use could compensate for a system that did not perform a useful function". In Precision

Agriculture, technology adoption appears to be more complicated since a technology that performs a useful function is not enough, or in other words, a technology could be adopted if it is perceived useful, easy to use and there is a service consultancy that supports the beginners.

The research conducted here needs further investigation in order to evaluate how farmers' perception will change after a usage experience. In fact the findings of TAM conducted on a pre-prototype technology did not reflect precisely the future usage behavior. The prediction of usefulness could be stable, because it could be recognized even from target users who have received just some information, but the perception of ease of use is the most likely to change because a correct evaluation of this factor should be based on a direct usage experience (Davis and Venkatesh, 2004).

5. Conclusion

This research presents some critical aspects and, at the same time, adds some interesting information in understanding the behavioral attitudes which could move farmers to adopt PA technology.

The total variance explained by this model is "only" the 46.8%, so that a first remark is the necessity to improve this model to better fit the real farmers' behavioral attitude towards technology. This result represents a not optimal representation of real farmers' behavior but, anyway, a good starting point. In fact this research faced the difficulty to investigate the farmers' perception toward a pre-prototype technology, before a usage experience, while prior research has focused mainly on socio-demographic and financial variables and their impact on PA technology adoption, but with very little attention to the main factors that influenced the decision to adopt a technology or not.

Since PA technologies are still not widespread (Lamb et al., 2008) it is important to understand farmers' perceptions about them, in order to understand the causes of the low adoption rate and the opportunity to improve this situation.

This work first confirmed the core of adoption theory already seen in Precision Agriculture, that farmers must perceive PA technologies as useful and easy to use in order to make them become adopters (Aubert et al., 2012). Further, this research reveals the important influence of Support, adding to the two main factors, so that it is as relevant as PU and PEU.

These results provide precious information for experts, researchers and agricultural services. Even if the market of PA is not so large in fact, this could be an opportunity for people and researchers that are expert in PA because the need of support represented here must be thought as an incentive to create small firms which sell consultancy other than technologies (Jochinke et al., 2007).

Furthermore, from this information it is possible to argue some policy implications. Stakeholders and PA technology developers should create new devices with the integration of the three characteristics expressed by farmers: usefulness, ease of use and a service support. The farmer's perception is the most important reference point to take into account. What is useful for farmers must be investigated by specific research programs able to extract the farmer's need, after that the task of technology producers and developers is to create a technology that could fit the current agricultural practices (ease of use) so that farmers become able to use a PA technology (Hudson and Hite, 2003). Finally, as PA technologies seemed to create new questions rather than providing solutions to their problems, farmers need help to interpret all the data provided by those technologies (Stafford, 2000).

Farmers' perceptions of usefulness and ease of use about the pre-prototype PA technology depicted in this research indicate just a technology that could be useful for fruit growers, and this could be an important starting information for further technology researches.

Certainly, the model theorized was not complete and shall be enriched with other new factors and antecedents to those already detected. The perception of cost, for example, is an important variable that must be investigated since the high cost of PA technologies was indicated as one of the major limitation to their diffusion (Hudson and Hite, 2003; Reichardt and Jürgens, 2009).

A Wireless Sensor Network for Fruit Growth Monitoring and Schedule Irrigation

1. Introduction

1.1 Wireless Sensor Network

In recent years, advances in miniaturization; low-power circuit design; and simple, low power, yet reasonably efficient wireless communication equipment have been combined with reduced manufacturing costs to realize a new multifunctional sensor nodes that are small in size and communicate with each other through short radio distances.

These tiny sensor nodes consist of sensing, data processing and communication components and have determined the birth of a new version of wireless networks named Wireless Sensor Networks (WSN).

A WSN is composed of a large number of sensor nodes that are densely deployed either inside the phenomenon or very close to it. The position of sensor nodes can be predetermined to guarantee uniform sensing of a defined area or they can be randomly deployed in inaccessible terrains or in particular types of application as in disaster relief operations. In this last case it is necessary to create sensor network protocols and algorithms that possess self-organizing capabilities. A WSN is a system comprised of radio frequency (RF) transceivers, sensors, microcontrollers and power sources (Akyildiz et al., 2002). It can operate in a wide range of environments and provide advantages to monitor a situation, a process or a room from remote in real time, so that it makes possible controlling and acting promptly when some problems occur.

Typical application scenarios for WSNs include a sink that acts as coordinator of the network and can trigger periodically the nodes, but especially collects the observations received by them and transmits the data to the user through wireless or wired link.

There are two main types of networks:

- Star network. Each sensor can transmit the observations directly to the sink.
- Mesh network. The nodes are positioned in a large area and the farther ones do not have a radio visibility with the coordinator. In this case each node acts both as sensor and as router to forward the data of the neighbor nodes toward the sink.

An important feature of sensor networks is the cooperative effort of sensor nodes. These instead of sending the raw data to the sink, use their processing capabilities to locally carry out simple computations and transmit only the required and partially processed data.

WSNs are suitable for a wide range of applications in military, health, home, industry, agricultural and a lot of other fields. For example in health, sensor nodes can be deployed to monitor and assist disabled or old patients. Realization of this and other sensor network applications require *ad hoc* networking techniques. Although many protocols and algorithms have been proposed for traditional wireless *ad hoc* networks, they are not well suited to the features and application requirements of sensor networks. The main differences between Star and Mesh networks are:

- The number of sensor nodes in a sensor network can be much higher than that in an *ad hoc* network. These components are usually densely deployed.
- There is a high probability that sensor nodes can fail.
- In some cases the topology of a sensor network changes very frequently.
- Sensor nodes mainly use a broadcast communication, whereas most *ad hoc* networks are based on point-to-point communications.
- Sensor nodes are limited in power, computational capacities, and memory.

The main factors that it is important to consider to planning or to design algorithms and protocols for this type of networks are (Ruiz-Garcia et al., 2009):

- Fault Tolerance. It is important to consider that some sensor nodes may fail or can be blocked due to lack of power, or have physical damage or environmental interference. The failure of sensor nodes should not affect the overall task of the network. Fault tolerance is the ability to sustain sensor network functionalities without any interruption due to sensor node failures.
- Scalability. The number of sensor nodes deployed in studying a phenomenon could be very high (hundreds or thousands) for particular applications. Algorithms and protocols created for this type of networks must consider this aspect as well as their high density that can range from a few sensor nodes to several hundred in a region that can be less than 10m in diameter. Usually in those areas where there is a high density of nodes it is quite easier to design energy-efficient algorithms;

the great challenge is to design minimum-power-consumption algorithms in those networks where there is a small redundancy of nodes.

- Costs. Since wireless sensor networks consist of a large number of sensor nodes, the cost of a single node is very important to justify the overall cost of the network. Obviously this cost has to be as low as possible. Actually the cost of a single wireless node is roughly 20 euro. The main producers are Texas Instruments, Crossbow, St Microelectronics, Zensys, FreeScale and others. With the development of technology the cost of a single node should be much less than 1 euro.
- Hardware Constraints. A sensor node is composed of four basic components: a sensing unit, a processing unit, a transceiver unit and a power unit. It is possible to include additional components as a location finding system, a power generator and a mobilizer. Sensing units are usually composed of two subunits: sensors and analog-to-digital converters (ADCs). The sensors observe a determined phenomenon and produce the analog signals that are converted into digital form by the ADC, and subsequently are elaborated by the processing unit. This unit, which is generally associated with a small storage unit, manages the procedures both to extract information from the observations and to collaborate with the neighbor nodes in the mesh networks, in order to guarantee reliable communications with minimum power consumptions. A transceiver unit connects the node to the network. It contains the transmitter and receiver, usually tuned on Industrial, Scientific and Medical (ISM) frequency bands (433MHz, 800MHz and 2.4GHz). Power units may be supported by power scavenging units such as solar cells. Additional subunits are useful to particular types of application. Most of the sensor network routing techniques and sensing tasks require knowledge of location with high accuracy. In these types of applications, it is important that a sensor node has a location finding system. A mobilizer can be useful to move sensor nodes in those applications where it is required to monitor a mobile phenomenon. it is important that all of these units and subunits be included into a small module.
- Environment. Sensor nodes are usually densely deployed either very close or directly inside the phenomenon to be observed. Therefore, they usually work unattended in remote geographic areas. They may be working in the interior of large machinery, at the bottom of an ocean, in

a biologically or chemically contaminated field, in a battlefield beyond the enemy lines, and in a home or large building. For some of these scenarios, sensor nodes are thrown for example by an airplane and assume random positions. It is important that they can auto- organize in order to create an efficient and reliable network. In scenarios accessible by man, nodes are positioned one by one in the sensor field to create a desired network topology.

- Transmission Media. In a mesh network, communicating nodes are linked by a wireless medium. These links can be formed by radio, infrared, or optical media. To enable global operation of these networks, the chosen transmission medium must be available worldwide. As above described, the three frequency bands actually utilized are 433MHz, 800MHz and 2.4GHz that are no-license ISM bands. Another possible mode of internode communication in sensor networks is by infrared. Infrared communications is license-free and robust to interference from electrical devices. Moreover the transceivers are cheaper and easier to build. The big problem is that this type of transmission media require a line of sight between the sender and receiver (so as the optical media), that is impossible to assure in environments as those described in the previous point.
- Power Consumption. Usually the wireless sensor node can only be equipped with a limited power source (in most cases two AA batteries). In some application scenarios, replenishment of power resources might be impossible. Sensor node lifetime, therefore has a strong dependence on battery lifetime. In a mesh network, each node plays the dual role of data originator and data router. The malfunctioning of a few nodes can cause significant topological changes and might require rerouting and reorganization of the network. Hence, power conservation and power management take an importance greater than reliability of communications. The main task of a sensor node in a sensor field is to detect events, perform quick local data processing, and then transmit the data. Power consumption can hence be divided into three domains: sensing, communication and data processing.

The standard communication protocol is IEEE802.15.4 which defines the specifications relatively to Medium Access Control (MAC) included in a WSN. It uses carrier sense multiple access with collision avoidance (CSMA-

CA) medium access mechanism and supports star as well as peer-to-peer topologies.

The IEEE802.15.4 standard imposes a range of transmission power between −32 and 0 dBm (milli-Decibel). Two different types of devices can participate in an IEEE802.15.4 network; a full-function device (FFD) and a reduced-function device (RFD). The FFD can operate in three modes serving as a personal area network (PAN) coordinator, a coordinator, or a device. An FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD. An RFD is intended for applications that are extremely simple, such as a light switch or a passive infrared sensor; they do not have the need to send large amounts of data and may only associate with a single FFD at a time. Consequently, the RFD can be implemented using minimal resources and memory capacity. Usually a WPAN shall include at least one FFD, operating as the PAN coordinator.

Depending on the application requirements, the IEEE802.15.4 standard may operate in either of two topologies: the star topology and the peer-to-peer topology. In the star topology the communication is established between devices and a single central controller, called PAN coordinator. A device typically has some associated application and is either the initiation point or the termination point for network communications. A PAN coordinator may also have a specific application, but it can be used to initiate, terminate, or route communications around the network. The PAN coordinator is the primary controller of the PAN. All devices operating on a network of either topology shall have unique 64bit addresses. This address may be used for direct communication within the PAN, or a short address may be allocated by the PAN coordinator when the device is associated. The PAN coordinator might often be mains powered, while the devices will most likely be battery powered. Applications that benefit from a star topology include home automation, personal computer (PC) peripherals, toys and games, and personal health care.

The peer-to-peer topology also has a PAN coordinator; however, it differs from the star topology in that any device may communicate with any other device as long as they are in range of one another. Peer-to-peer topology allows more complex network formations to be implemented, such as mesh networking topology. Applications such as industrial control and monitoring, asset and inventory tracking, precision agriculture, and security would benefit from such a network topology. A peer-to-peer network can be *ad hoc*, self-organizing, and self-healing. It may also allow multiple hops to route messages from any device to any other device on the network. Such functions can be added at the higher layer, but are not part of the standard. Since in the greater part of the applications, devices are battery powered, and battery replacement or recharging in relatively short intervals is impractical, power consumption is a primary aspect. The standard was developed with limited power supply availability in mind. Battery-powered devices will require duty-cycling to reduce power consumption. These devices will spend most of their operational life in a sleep state; however, each device periodically listens to the RF channel in order to determine whether a message is pending. This mechanism allows the application designer to decide on the balance between battery consumption and message latency. Higher powered devices have the option of listening to the RF channel continuously.

From a security perspective, wireless *ad hoc* networks are no different from any other wireless networks. They are vulnerable to passive eavesdropping attacks and potentially even active tampering because to access a physical communication channel it is not required to participate in communications. The very nature of *ad hoc* networks and their cost objectives impose additional security constraints, which perhaps make these networks the most difficult environments to secure.

Devices are low-cost and have limited capabilities in terms of computing power, available storage, and power drain; and it cannot always be assumed they have a trusted computing base nor a high-quality random number generator aboard. Communications cannot rely on the online availability of a fixed infrastructure and might involve short-term relationships between devices that may never have communicated before. These constraints might severely limit the choice of cryptographic algorithms and protocols and would influence the design of the security architecture because the establishment and maintenance of trust relationships between devices need to be addressed with care. In addition, battery lifetime and cost constraints put severe limits on the security overhead these networks can tolerate, something that is of far less concern with higher bandwidth networks. Most of these security architectural elements can be implemented at higher layers and may, therefore, be considered to be outside the scope of the standard.

With regard to the implementation layer, WSN applications are divided into two main categories:

- Applications that use a predefined network layer implementation and need the creation of the user application.

- Applications that are created directly on MAC layer, where we need to implement both the network layer and the user application.

Relatively to the first category, at the moment, there are different producers that provide platforms with dedicated network protocols. A number of important electronic companies in 2004 have created an alliance named Zigbee, with the goal of defining a common network protocol. The WSN used in this research belongs to the second category and was developed by Winet srl (Cesena, Italy).

1.2 Wireless Sensor Network in Agriculture

WSNs have found several applications in agriculture, especially recently as a consequence of reducing cost of the sensors and technologies and the engineering achievements in developing smaller devices, radio frequency and digital circuits.

In agriculture, the radio frequency faces challenges due to the placement of nodes for wide-area mesh coverage and reliable link quality above crop canopies. In this environment radio propagation is complex due to multipath propagation, shadowing and attenuation. WSN must be able to operate in a wide range of environments such as bare fields, vineyards, orchards, from flat to complex topography and over a range of weather conditions, all of which affect radio performance (Correia et al., 2013; Li and Gao, 2011). What must be avoided and/or absolutely detected are erroneous measurements, wrong information and deficiencies in radiowave propagation, maybe occurring when battery voltage was low, or for climate conditions as humidity, precipitation and low temperatures, or because the woody plants and the density of leaves impede transmission (Ruiz-Garcia et al., 2009).

The whole list of agricultural applications is: Climate Monitoring, Farm Machinery, Pest Control, Irrigation, Greenhouses, Livestock, Food Industry, Cold Chain Monitoring and Traceability, and more generically, Precision Farming (Ruiz-Garcia et al., 2009).

In the specific sector of fruit production, WSNs have been mainly used for irrigation purposes. The systems that have been installed to modernize irrigation have been based upon technological solutions like sensors monitoring soil water content, climate conditions, meteorological parameters, sap flow and trunk diameter variation (Conejero et al., 2007; Damas et al., 2001; Di Palma et al., 2010; Dursun and Ozden, 2011; Jones, 2004; Martinelli et al., 2009; Ortuño et al., 2010; Parameswaran et al., 2012; Pons et al., 2008; Torre-Neto et al., 2005). A particular application of an "Irrigation WSN" was that designed by Pierce and Elliot (2008) in order to monitor air temperature and protect apple trees, in the delicate flowering period, from frost events.

1.3 Objective

This paper is part of a long-term effort to introduce precision fruit production. It describes the architectural solutions, with particular focus on hardware implementation and communication protocol design, of a Wireless Sensors Network designed for orchard irrigation purposes.

While remote sensing provides a relatively high degree of spatial resolution, it is expensive and it requires very accurate installation and long calibration procedures. Therefore, to supervise some event for long time, WSNs are the natural choice as the cutting edge technology that can quickly respond to rapid changes of relevant physical parameters and send them to a remote center for further elaboration and alerting. Despite having this potentiality, in agriculture WSN functionality has been tested for short experimental periods, as days or weeks (Ruiz-Garcia et al., 2009), while in this work the technical applicability of the system in a real orchard situation has been investigated, i.e. an Italian fruit farm in Emilia Romagna region for a long period corresponding to the long second kiwifruit development phase (Hall et al., 2006, 2002; Morandi et al., 2012a).

In developing a WSN for fruit growth monitoring there are several crucial aspects that need to be considered. Here, we summarize the most important challenges inspiring our design:

- Long network lifetime is required to reduce human intervention and risks, e.g., for battery replacement.
- Fruit growth is a slow physical process that requires continuous monitoring for very long periods. This makes energy consumption challenging.
- The WSN operates in harsh environments as "real" commercial orchards, where node failures may occur unexpectedly. Synchronization and routing algorithms need to be fault tolerant to guarantee network robustness.
- To manage network lifetime, network parameters need to be controlled

and set up remotely and autonomously: the acquisition interval, the number of retransmissions allowed, the sensors to be activated, etc.

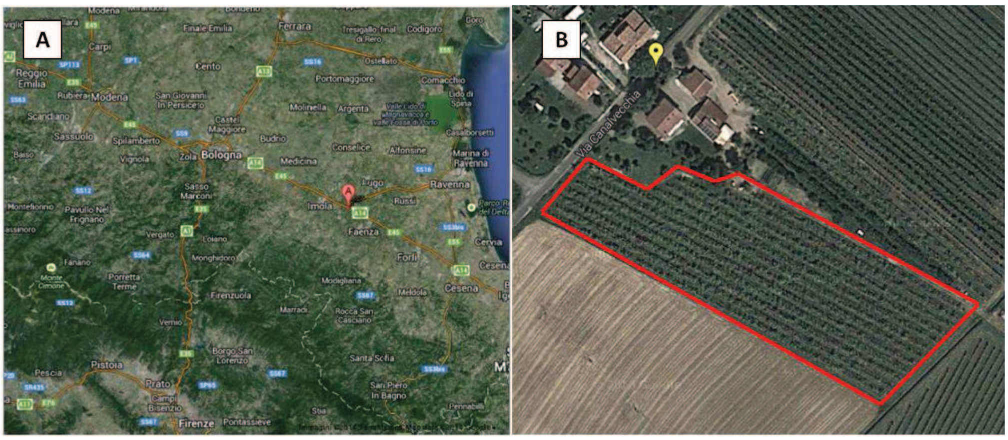
In this work, we propose and analyze a WSN that adopts a synchronization procedure and a novel fault recovery (FR) protocol, all tailored for the specific monitoring of fruit growth by low cost devices (Morandi et al., 2007). The WSN application was part of an Italian funded research program (PRIN 2009) designed to evaluate xylematic and floematic flows in kiwifruit trees exposed to different irrigation treatments. The aim of the developed WSN is to address most of the significant challenges of the monitoring scenario, with available off-the-shelf communication technology. The focus of this work is the description of the entire system and analyzing its performance, while the processing of physiological data collected for fruit growth analysis is the subject of future works.

2. Scenario and sensor Network Description

2.1 Orchard

The kiwifruit orchard (*Actinidia deliciosa* cv. Hayward) was located in Solarolo, in the Eastern part of the Emilia Romagna region, in the Po Valley (Italy, Figure 1A). The year of planting was 1996, therefore the orchard was 17 years old, the training system was Pergola Trellis (2 x 5 m) and the total area was 0.95 hectares (Figure 1B).

Figure 1. Location of kiwifruit orchard (Solarolo, Emilia Romagna, Italy).



2.2 Sensors adopted

The WSN adopted in Solarolo is composed by 9 wireless nodes, one of which acts as network coordinator (NC). All the nodes, but NC, are equipped with 3 or 4 fruit gauges (Morandi et al., 2007) for a total number of 27 devices. The NC acts as a gateway towards the Internet through a general packet radio services (GPRS) modem to guarantee the access to the remote unit (RU). The coordinator is also equipped with a weather station (Davis Instruments, CA, USA) which includes several sensors: air thermometer (range -20/+80 °C, acc. ±0.2%), air hygrometer (range 5/95%, acc. ±2%), rain gauge (res. 0.2 mm), and wind gauge (speed acc. ±5%, dir. acc. ±4%).

A schematic view of the monitoring system is reported in Figure 2. Red points indicate sensor nodes while the blue one indicates the NC. Since the WSN was adopted for a research program the nodes were located close to each other in order to respect the plot partitioning. The longest distance was between the node 06C1 and the NC, corresponding to 22 m on the same row, while the nodes 3677, E4D4 and EA30 were mounted on trees in front of the NC, in the next row (5 m).

The transceiver nodes (red points) were positioned under the canopy, hung on the wire sustaining the central leader of the tree and the irrigation system (Figure 3A), while the NC was positioned above the canopy because it was connected with the weather station (Figure 3B). The difference in height between sensor nodes and NC was approximately 2 m.

Figure 2. The WSN installed in the kiwifruit orchard. Numbers in box are the MAC addresses of nodes.

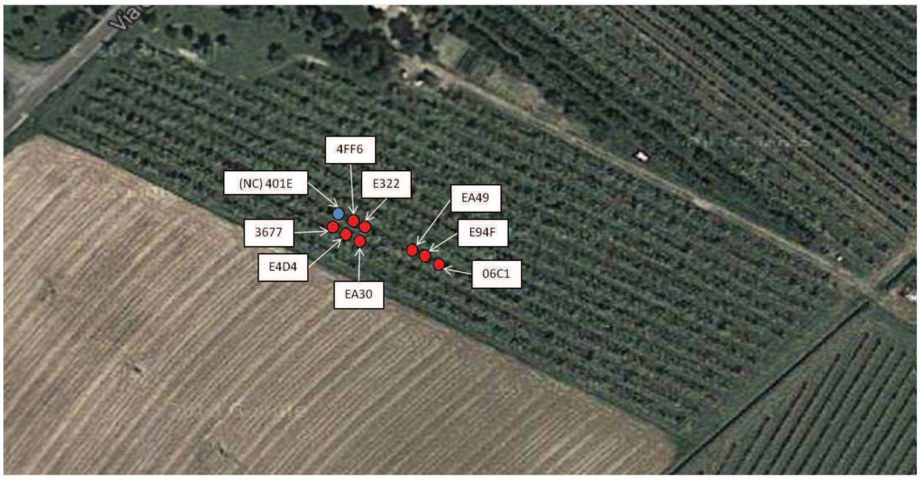
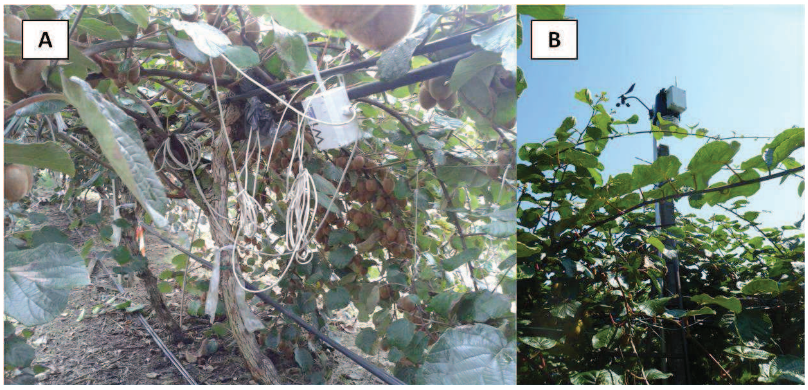


Figure 3. Position of transceiver node (A) and NC (B).



2.3 The network node

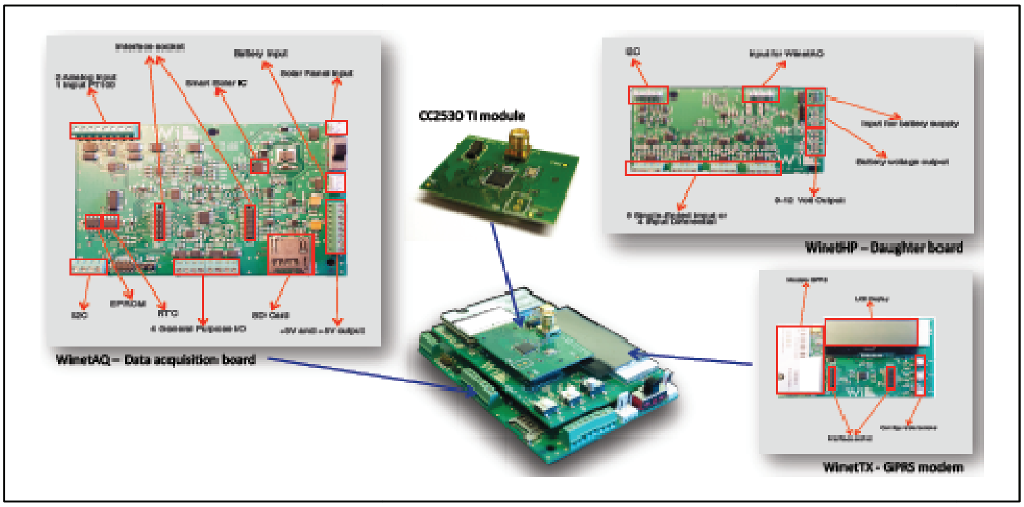
The main components of a network node are the microcontroller, a transceiver, an external memory, a power source and one or more sensors. The network was developed by Winet srl (Cesena, Italy). It included a data acquisition board (WinetAQ), a transmission board (WinetTX), and an interface board (WinetHP) (Winet srl, http://winetsrl.com/hardware_e.html).

The core of each sensor node is the Texas Instrument chip CC2530, which includes a 2.4GHz RF transceiver compliant to the standard IEEE 802.15.4, and supports three low-power modes (Texas Instrument, 2011).

The physical and MAC layer functionalities of each sensor-node are compliant to the IEEE802.15.4 standard (IEEE Computer Society, 2003). As far as the network layer functionality is concerned, in this project we adopted an energy efficient *ad hoc* protocol, developed by Winet srl, with characteristics similar to ZigBee protocol stack but with much lower power consumption, to guarantee a higher network lifetime.

The sensors adopted were of different type and their outputs are of different nature: the fruit gauges and air thermometer were resistive, the hygrometer was tensiometric, the anemometer and the rain gauge were pulsed. All these quantities were then conditioned to be digitized by the analog-to-digital converter (ADC) and successively inserted in the payload of a packet. The wireless node developed has a multi-layer structure to be customized on the monitoring needs (Figure 4).

Figure 4. The multi-layer architecture of the sensor node developed. WinetTX contains the GPRS modem therefore it was only in the NC, WinetHP is the interface board, in the node connected to the fruit gauges.



2.4 The batteries and the solar panel

Sensor nodes were equipped with 6V/2.8Ah lead batteries, except for the NC which had a 6V/40Ah battery and a 5 W solar cell. The solar panel and the battery capacity have been chosen to satisfy the very high energy consumption of the GPRS modem.

2.5 Remote Management

In the RU data were saved on a MySQL DBMS for further visualization and post-processing. The RU was accessible through a web page with different sections:

- The home page shows the most recent data collected with a time-stamp and the related MAC address. It is also possible to monitor network parameters such as the battery level and the received signal strength (RSS) of radio links.
- The *Plot section* shows the time series of monitored parameters and of battery levels.
- The *Warning section* is a configuration page where it is possible to set up thresholds on monitored parameters and/or its rate of change in time, to detect an alarm situation.

- The *Log section* showed messages referred to network behavior, such as the activation of Fault Recovery (FR) procedures, etc. These information were useful for network maintenance.

3. Network mechanism for robustness and long lifetime

3.1 Network self-organization

Each node had a MAC address of 2 bytes for data association and network management. The self-organizing protocol defined a tree logical network topology where each node had one *father* node and may have one or more *children* nodes.

Table 1. MAC Addresses and Logical Addresses during the monitoring campaign (1st July – 3rd October, 2013).

MAC Address	Logical Addresses
401E	AABB
4FF6	05F6 (1 Jul – 7 Jul) 04F6 (12 Jul – 15 Jul) 03F6 (15 Jul – 23 Jul) 01F6 (23 Jul – 3 Oct)
E94F	014F (1 Jul – 27 Jul; 26 Aug – 31 Aug) 034F (30 Jul – 26 Aug) 044F (23 Jul; 27 Jul – 28 Jul; 3 Sep – 3 Oct)
E4D4	01D4 (1 Jul – 23 Jul) 04D4 (23 Jul – 5 Aug) 06D4 (5 Aug – 3 Oct)
E322	0422 (1 Jul – 10 Jul) 0322 (12 Jul – 23 Jul) 0222 (23 Jul – 26 Aug) 0622 (26 Aug – 2 Oct)
EA49	0249 (1 Jul – 15 Jul; 23 Jul – 30 Jul; 26 Aug – 3 Oct) 0449 (15 Jul – 23 Jul; 30 Jul – 26 Aug)
EA30	0230 (1 Jul – 23 Jul) 0530 (23 Jul – 3 Oct)
06C1	03C1 (1 Jul – 30 Jul; 26 Aug – 3 Oct) 05C1 (30 Jul – 26 Aug)
3677	0377 (1 Jul – 10 Jul; 23 Jul – 29 Jul) 0477 (15 Jul – 23 Jul) 0677 (31 Jul – 3 Oct)

To better reflect the network organization, the MAC address was paired with a logical address of the same length. In particular, the least significant byte of the logical address coincided with the one of the MAC address, while its most significant byte was the level to which the node belonged to, in the logical network topology. The only exception was the NC, which was the sole root at level 0, hence its logical address was simply AABB (Table 1). The protocol allowed only communication toward nodes at a higher level (i.e., from Level 5 to Level 4) with exception of the FR phase. In this field-test the WSN needed to be re-organized because of searching for a better radio linkage and for 2 battery replacement. In fact, two extraordinary events occurred when nodes presented some problems due to a new hardware component (multiplexer) that caused a higher power consumption. Gradually, during the first month (July), was developed a better software release with a new setting adapted to the new hardware. A functioning version was obtained between July 23rd and August 5th and, as can be noted in Table 1, from the 5th until the 26th of August the logical addresses of all nodes were stable. After the 26th of August just the node with MAC address E94F changed its logical address on the 3rd of September.

Figure 5. The WSN hierarchical logical topology at July 1st 2013 (A) and August 5th 2013 (B, C).

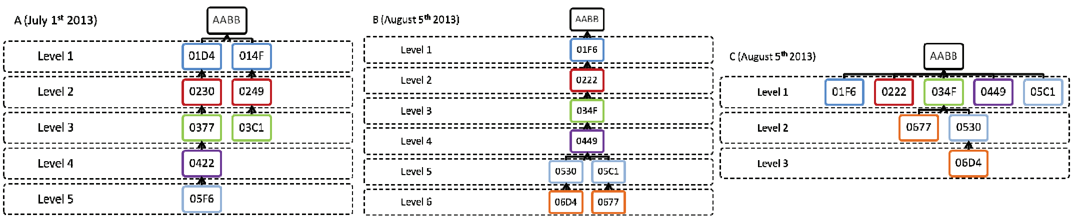


Figure 5 depicts the hierarchical logical topology of the WSN at two different times of summer 2013, the 1st of July (A) and, after one month, the 5th of August (B), after the re-configuration events occurred. These changes involved only the logical addresses, not the MAC ones. The Figure 5B represents the WSN configuration after the installation phase on the 5th of August. After this installation phase, the logical topology changed (Figure 5C) because of weak linkages between a node and a higher level one. The consequence was that nodes which were at lower level delivered their data directly to the coordinator, like nodes 034F, 0449, 05C1. The WSN performance, presented in chapter 4, has been calculated referring to the configuration of the period 5^{th}-26^{th} August 2013 (Figure 5B and C), the longest with a stable configuration in the core of summer season.

The self organization protocol was driven by the association phase (AP) which established the logical topology of the network. In this phase, a node scanned the radio channel to search a father node with a good link quality. The threshold on the received power, adopted to discriminate between good or bad link quality in the AP, was a -80 dBm to guarantee good network connectivity and prevent FR procedures, which were energy consuming. Then, if the father node was available, it created a logical address and transmitted it to the children node. In the AP, if a node did not find any father, it entered into a fault recovery (FR) phase.

Once the logical topology was completely formed, each node could be in one of four possible phases, which in normal conditions were visited cyclically:

- Association phase (AP). A node could accept node's association requests to become part of the network, or accepted nodes that have been reset.
- Receiving phase (RP). The node received all the data which have been sent from children nodes, and stored them into the EEPROM.
- Transmission phase (TP). The node read the sensors and transmitted the data to the father node, together with all the data gathered by the neighbor nodes previously stored in the EEPROM.
- Sleep phase (SP). The radio interface was turned off, the CC2530 module entered into low-power mode and neither transmission nor reception was possible.

Each phase corresponded to a specific temporal slot. In particular, in the fruit growth monitoring the association phase had a duration T_{ASS} = 2000 ms; the receiving slot had a variable duration, T_{RX}, which depended on the amount of data transmitted by children nodes, with a minimum value of $T_{RX,min}$ = 2100 ms; the data transmission slot, T_{TX}, was also varied dynamically based on the volume of data to be passed to the father node; the rest of the time, the nodes were in SP with duration T_{SLEEP}. The acquisition interval had a fixed duration ($T_{ACQ} = T_{ASS} + T_{RX} + T_{TX} + T_{SLEEP}$) and could be set remotely on the RU. Note that T_{ACQ} was the time interval between two consecutive data acquisitions and was fetched by the NC during each GPRS connection activated for data transfer. To disseminate such information to the whole network, there was a dedicated time slot where all the nodes wake up simultaneously and exchanged T_{ACQ} in broadcast.

3.2 Network synchronization

Network synchronization guaranteed the alignment of temporal slots of different phases between nodes. In particular, the alignment ensured that whenever a child node entered in a TP, the father node was in the RP. To this aim, the nodes had different wake up times from the SP, based on the level they belonged to.

Synchronization was based on an astronomical clock provided on each node. The start up phase of the network began turning on the NC which would fetch the date and time from the RU through the GPRS connection. This information was used to set the NC clock and were propagated through the network during the AP of each node, so as to guarantee updated time references. In particular, after completing the association and then receiving the logical address from the father node, the child executed a first reading of the sensors, transmitted all the collected data and waited for the signal of successful reception from the father (Acknowledge, ACK), containing updated time and date.

Because of the FR mechanisms, it is possible that a node changed the level while keeping its short address, to avoid a new association. Because of such feature, there was no direct link between a node level and a suitable wake up time to allow a synchronization with the upper level nodes. For this reason, inside an ACK packet, every father node sent, together with date and time, even its wake up time. By wake up time it was possible to understand how long it took to switch from sleep to active mode. Following such value, the child node set its wake up time.

3.3 Fault recovery (FR) procedure

The fault tolerance mechanism was the management of events which caused nodes isolation such as low quality of radio links with all neighbors, a malfunctioning due to a failure or low battery charge. Because of the environment, the very long network lifetime, and the lack of human intervention, these situations may occur unexpectedly. The FR procedure was based on the following criteria:

I. In the TP, a node had knowledge of the correct data delivery when it received an ACK packet. Every time a node did not receive the ACK, it kept all the data in its memory to deliver them during the following awakening. If the ACK was not delivered for two consecutive times, the link was declared unreliable and the node had to look for a new father to communicate with.

II. A node searched for a new father among the ones on an upper level.

III. To search for a new father it was not necessary to start a new AP. Instead, a special packet containing the following information was sent in broadcast mode:

   4. The level, L_f, the new father node had to belong to;
   5. The wake up time, T_f, of the new father node.

   During the first search, L_f is simply the level right above the one the node belonged to. In case there were no fathers available in such level, the search continued to a higher level. Following such mechanism, a node was able to rise through the network hierarchy, if needed, to level 1.

   According to the synchronization mechanism described in section 3.2, if a node rose up from one level to another, it had to update its awakening time to be synchronous with the new father.

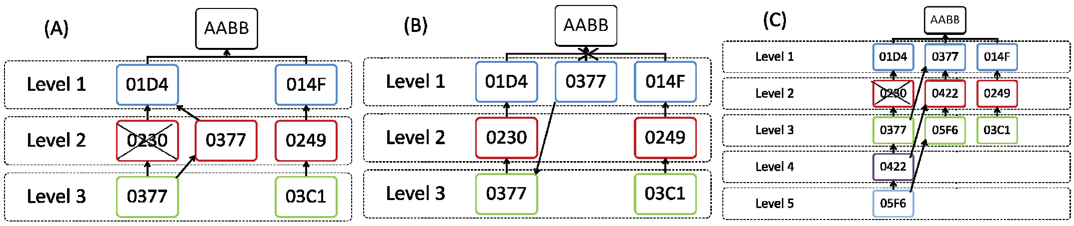
IV. If III failed, i.e., after reaching level 1 a communication towards the NC was still not possible, the node became orphan and went back to its initial level to start again a new search and, if necessary, climbed again the hierarchy. As soon as it became orphan, the node set its sleep interval, T_{SLEEP} to 1 minute, irrespective of its previous value. This action, forced the orphan to have short sleep duration to quickly recover the synchronization with a candidate father. In fact, an orphan could have been isolated from the network for several minutes and could have missed the packet containing an updated T_{ACQ} fetched from the RU, or could be subject to a temporal drift. Once the orphan found a father node, its sleep time is restored according to the updated T_{ACQ}.

   The second parameter, T_f, guaranteed that a father node belonging to a superior level with the correct synchronism was found.

V. An orphan never replied to their children with an ACK. This criterion forced children to look for another father to avoid isolation from the rest of the network.

To better illustrate the FR procedure, Figure 6 depicts three possible situations: A) the migration of a single node to an upper level; B) a node going back to the initial level after becoming orphan; C) the migration of a group of nodes. In particular, in Figure 6A, node 0377 after transmitting twice its data to node 0230 without receiving any ACK, started looking for another father at level 2, but since it could not find it, it migrated to the upper level. Figure 6B shows node 0377 which could not communicate anymore with its father 0230. Hence, the node started migrating from level to level, until reaching level 1, but since the transmission toward the NC failed, it became orphan and went back to level 3, where it started a new search. Finally, in Figure 6C, the node 0377 could no longer communicate with its father 0230 and since it did not find any other fathers at level 1, it migrated to the level 1. Since this node did get data from the child node 0422, which in turn was node 05F6's father, even those nodes migrated to upper levels.

Figure 6. Fault recovery mechanism: A) level migration: B) go back to the initial level; C) group level migration.



4. Results

In this section are reported some statistics extracted by the analysis of data collected during the period between 5-26 August 2013 just to demonstrate the functionality, even if the system worked from the 1st of July until the 3rd of October 2013, for a total of 94 days.

4.1 Paths Statistics

An important metric to understand the behavior of the routing algorithm is the link utilization. More precisely, for each couple of nodes, A and B, we defined the percentage of packets sent (PPS) as:

$$\mathrm{PPS}(A,B) = \frac{\mathrm{N°\ of\ packets\ sent\ from\ } A \mathrm{\ to\ } B}{\mathrm{total\ N°\ of\ packets\ sent\ by\ } A}$$

Such metric is reported in Table 2, where the rows refer to nodes in transmission mode, *A*, while columns refer to nodes in receiving mode, *B*. The PPS includes also the number of packets sent during the FR procedure to look for a father node (last column). Hence, since each can have only one father, the sum of values in each row is equal to 100%.

Table 2. Percentage of packets sent between any couple of nodes in the WSN (RX = receiving node; TX = transmitting node).

RX → / TX ↓	01F6	0222	034F	0449	0530	05C1	0677	06D4	AABB Coord.	Fault Rec. Mode	TOT
01F6									95.77%	4.23%	100%
0222	0.38%								95.77%	3.85%	100%
034F									93.94%	6.06%	100%
0449		20.83%	62.77%						6.99%	9.41%	100%
0530	2.10%	5.31%	81.76%						0.80%	10.04%	100%
05C1				50.14%					43.58%	6.28%	100%
0677		36.34%	57.81%						1.14%	4.70%	100%
06D4		1.82%	23.30%		66.81%				0.23%	7.84%	100%

As can be seen in Table 2, every node usually transmitted data to nodes belonging to a higher level. Consequently, node 01F6 from Level 1 delivered all its data to the NC (AABB) except for a certain percentage of times when it was in FR mode because the link was not reliable. The logical addresses shown in Table 2 are the ones after the reset (August 5th), since previously some of those nodes belonged to a lower level, for example 034F was 014F (Level 1) and 0530 was 0230 (Level 2). The nodes 0222 and 034F showed a favorite link toward the coordinator, even if they were in Level 2 and 3 respectively. Node 0530 had the highest FR rate among all nodes and it had a strong communication with 034F.

A different analysis is offered by Figure 7 which shows the most used paths towards the NC, considering only links with a PPS greater than 15%. To make some examples, data of node 05C1 were able to reach NC by hopping through nodes 0449 and 034F. Some nodes had different preferred paths, i.e. the node 0677 preferred to deliver its data to NC through the node 034F (57.81%), even if this node was further from the coordinator, and only as second choice node 0677 communicated with the closer node 0222 (36.34%).

Figure 7. Most used links, with PPS >15%, during the period August, 5-26 2013.

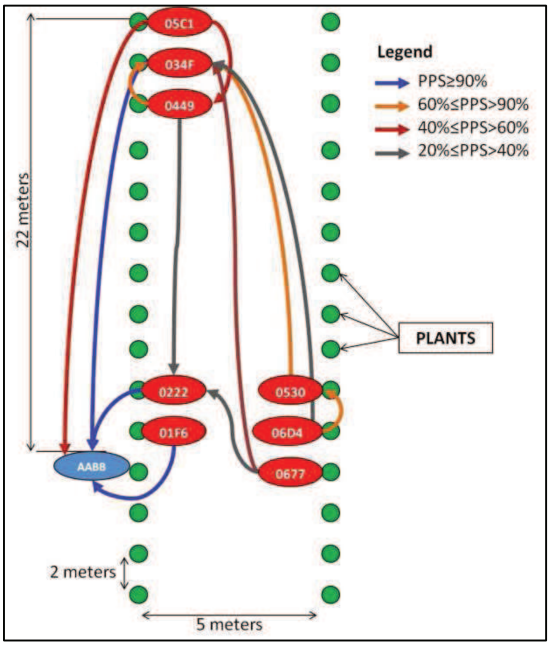


Table 3. Packet retransmission rate (PRR) for each radio link in the WSN (RX = receiving node; TX = transmitting node).

RX → / TX ↓	01F6	0222	034F	0449	0530	05C1	0677	04D4	AABB Coord.
01F6									4.23%
0222	0.24%								3.14%
034F		0.10%							4.82%
0449		0.78%	2.88%						1.46%
0530	0.49%	1.78%	0.94%						0.22%
05C1				1.29%					1.43%
0677		0.71%	0.90%						0.76%
06D4		0.93%	0.75%		0.28%				0.14%

4.2 Packet statistics

A metric that quantifies the link quality, at network level, between two nodes, A and B, is the packet retransmission rate (PRR), defined as:

$$\mathrm{PRR}(A,B) = \frac{\text{N° of packets retransmitted from } A \text{ to } B}{\text{total N° of packets sent by } A}$$

Table 3 shows the PRR for each link. The PRR values can be related to data provided in Table 2, since links with a high PRR will be, in general, the least used. There were of course the effects of node associations, battery level and also temporal fluctuations of radio channels, that could cause a non perfect correspondence between PRR and PPS. For example, node 0449 communicated with node 034F for 62.77% of times, and with node 0222 for 20.83% of times, but the first link had a PRR higher than the second one.

4.3 Radio link statistics

From the radio propagation point of view, the Received Signal Strength (RSS) is the most used and easy to measure parameter that can be used to quantify the link quality (del Prado Pavon and Choi, 2003).

Table 4. Mean value and standard deviation (in italic) of RSS for each wireless link (values in dBm) (RX = receiving node; TX = transmitting node).

RX → **TX ↓**	**01F6**	**0222**	**034F**	**0449**	**04D4**	**0530**	**05C1**	**0677**	**AABB Coord.**
01F6									-71.9 *(6.1)*
0222	-65.3 *(4.3)*								-54.2 *(2.9)*
034F									-81.9 *(6.2)*
0449		-96.8 *(1.7)*	-73.3 *(3.4)*						-86.2 *(7.3)*
0530	-63.2 *(3.9)*	-54.9 *(0.3)*	-97.0 *(2.4)*						-82.8 *(3.7)*
05C1				-57.6 *(2.3)*					-83.7 *(4.8)*
0677		-75.7 *(3.7)*	-93.8 *(1.9)*						-61.8 *(0.9)*
06D4		-68.7 *(0.9)*	-95.3 *(1.6)*			-52.1 *(1.2)*			-68.8 *(0.4)*

In Table 4, the mean value and the standard deviation of the RSS for all links in the network are reported. As a reference, the receiver sensitivity of

CC2530 is -97dBm. As can be seen, the standard deviation of the RSS ranges from 0.5 to 7.3 dBm. Such values can be used to set up a proper fading margin for future installations of the WSN in similar environments.

Based on Table 4, it is also interesting to analyze the behavior of links to better understand the joint impact of propagation and protocol aspects to the formation of the network. As can be seen, the link between node 0222 and the NC had a greater mean RSS (-54.2) and a lower standard deviation (±2.9) than the link between node 01F6 and the NC (-71.9, ±6.1). Observing the position of these nodes in Figure 7, it is clear that such difference was not due to the distance, since both nodes were close to the NC. Rather, the difference lies in the fact that NC was positioned at 3 m height just above the node 01F6 while the node 0222 was a few meters far from the NC on the row. The weakest signals (less than -90 dBm) have been registered in 4 links, but it is interesting to observe, in Table 2, that the PPS values of two of these links (0530-034F and 0677-034F) were relevant since they covered respectively 81.76% and 57.81% of the packets transmitted by nodes 0530 and 0677.

4.4 Energy consumption

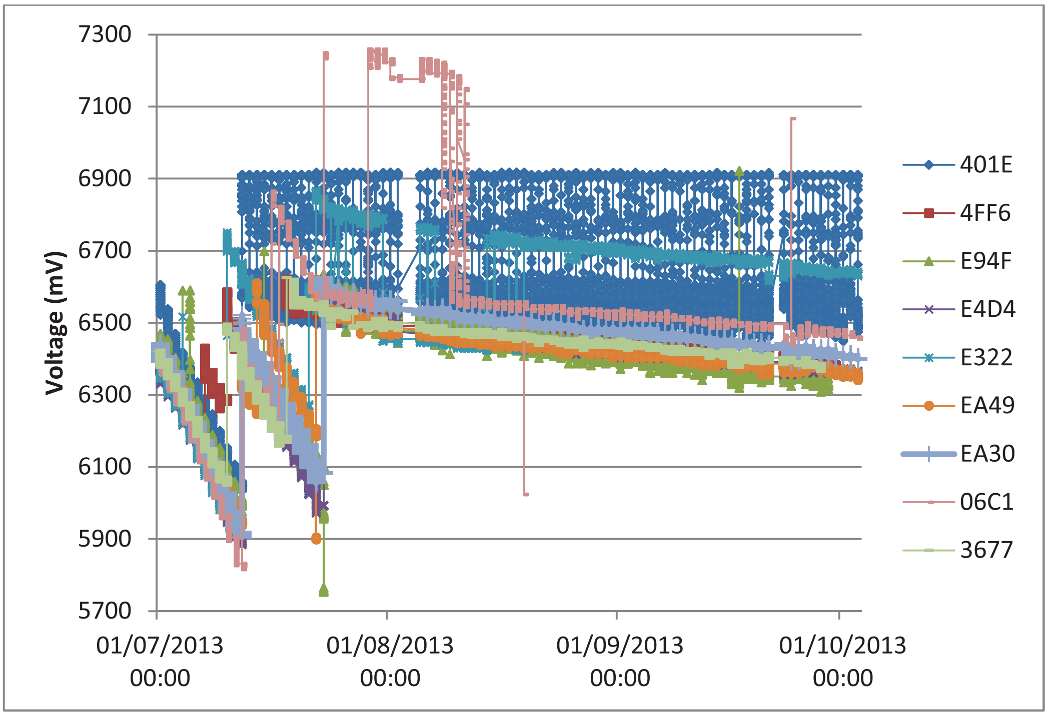
To complete the analysis of the network behavior and to estimate its lifetime, we collected battery voltages corresponding to each node, from July 1st until October 3rd 2013. Such values are reported in Figure 8. Note that the unequal initial values were due to different battery charge levels. As reference levels, a battery is considered fully charged when its voltage is above $V_C = 6.4$ V, and discharged when its voltage goes below $V_D = 6.1$ V.

As can be noted in Figure 8 nodes E322, 06C1 and the coordinator (401E) arrived at levels greater than 6.4 V when they were fully charged. The lecture of the battery level could report some error because the component that estimated battery level was not so precise as the one for reading the values detected by sensors. During the design phase of the board the policy was followed to save some money for this component, considered less important for research purposes.

The initial energy consumption was very fast, due to the problem observed during the first month (July). After having recharged batteries for two times (mid- and end of July) and having developed a new release of the software (adapted to the new hardware component), we reached a stable and functioning version of the WSN between July 23rd and August 5th. for the rest of the period, until the end of the monitoring campaign, node batteries voltage was above 6.3 V, confirming that node lifetimes can be safely estimated well beyond one season.

Regarding the NC, the solar panel provided enough power for all the season, since it could be oriented to south as best as possible. Considering this behavior, the coordinator lifetime is only limited by battery degradation, once in several years.

Figure 3. Battery voltage (mV) trends during the monitoring campaign (MAC addresses are indicated).



5. Conclusion

This work proposed a WSN designed for fruit growth monitoring in commercial orchard condition, to assess the possibility to provide real time information about the fruit development to researchers and fruit growers. All data recorded were sent to a RU and organized into a data-base that should be customized for the specific purposes of the end user, to be easy to adopt in the data processing phase. The WSN operated for 3 months with little human intervention and provided all the data necessary for full control of energy consumption and network/sensor maintenance. During the season several network statistics such as radio link quality, packet transmission statistics, routing path selection, and battery voltages were collected and analyzed. Such analysis demonstrates the effectiveness of the network protocols to manage self-organization, node failures, low link quality and unexpected battery depletion, and provide useful information for the network designer.

From the fruit grower point of view, the WSN of fruit gauges could be an interesting first step towards an even more precise irrigation management. This topic, paired with saving water, represented farmers' need besides a fundamental benefit for the whole society and the environment. Furthermore, farmers expressed the need of fruit growth monitoring, increasing the likelihood to reach the best fruit size, and forecast the final total production (Ellis et al., 2010). Starting from this information the actual goal for fruit growers and stakeholders should be reaching an optimization in the use of water in the frame of a "sustainable fruit farming", both economically and environmentally. In fact, it is important to respond to the market request and, at the same time, respect the environment by a precise management of available water that could lead to use only the amount of water effectively needed by the plants and the fruits. The fruit itself had rarely been considered for irrigation scheduling although it revealed its effectiveness (Corelli Grappadelli et al., 2012).

This work gave a first contribution to achieve a new concept of irrigation scheduling based on fruit growth monitoring. It has been demonstrated in fact that it would be possible to achieve an effective optimization of irrigation scheduling and water usage by fruit growth monitoring rather than by other environmental parameters (Corelli Grappadelli et al., 2012), since fruit was conceived as the best sensor of the whole tree (Morandi et al., 2012a,b).More research is necessary to realize this goal, and should be focused on: 1) improving the hardware components of the current fruit gauges to be easier to use; 2) set the right protocol in the data base, based on the clients' requirements, in order to simplify the data processing, and finally 3) test the WSN with longer distances between nodes in order to check its behavior in great orchards.

SECTION 4

1. General Conclusion

This research had the objective to examine the adoption of Precision Agriculture (PA) technologies and the initial development phase of a new technology for fruit production. The first section was a literature review aimed to define the framework of factors and drivers which affect the farmer's behaviour and decision to adopt a technology. The second section was a consumer survey aimed to detect the farmers' perceptions and their acceptance of a new technology not yet created, therefore in the pre-prototype phase. The third section described the first phase of development of a new technology. Every section represents a step of a process where the central idea is to search a method which allows to create new technologies that will be adopted.

In Section 1 the real situation was defined and the adopters and the non-adopters (or potential adopters) were examined, respectively by *ex post* and *ex ante* studies. This section is the baseline, because it offers the answers to these questions: Why are PA technologies not widely adopted? How is it possible to improve this low adoption rate? How is it possible to be sure that a new technology will be adopted?

Ex ante and *ex post* researches, if gathered together, give a complex but complete description of farmers' characteristics, motivations and behavioural factors which can move farmers towards the decision to adopt a PA technology or not.

Furthermore, a good connection was found between factors emerging from the review and the different phases of the Diffusion Process (Rogers, 1962) of a technology:

1. Awareness accounts for social factors, education, computer confidence, geography.
2. Interest: perceived usefulness, perceived ease of use.
3. Evaluation: size, soil quality, income, cost, previous experience, age.
4. Trial: trialability, observability, facilitating factors, perceived benefit, perceived ease of use.
5. Adoption: attitude to adopt, intention to adopt, adoption rate.

The process that leads from awareness to decision to adopt a new technology is the same for all the actors (Innovators, Early Adopters, Early Majority, Late Majority and Laggards), but the actors' characteristics account for the difference in time of adoption (Wejnert, 2002).

In fact, this profile is valid both for adopters and for non-adopters (or potential adopters), since the second ones are those farmers who perceived a technology as not useful, or difficult to use, or costly. Non-adopters have not yet found the "right" technology that fits their characteristics, and therefore they are "waiting" for the "right" technology that can be the solution to their problems. These informations are very important because they could have policy implications for companies intending to launch new technologies in agriculture, therefore the producers should have to consider all these parameters before, but also during and after, new technology development.

Usefulness and Ease of use of a new technology are two important factors which must be taken into account since they play a strong influence on the decision to adopt a technology. For this reason, R&D managers might investigate what farmers could perceive as useful for their activity before assigning huge financial resources to the research engineering. It is strategic to do this research in the first developing phase in order to check if the business idea is correct and fits the potential users' needs. This kind of survey can save time and money because it allows avoiding to direct the engineering effort towards a wrong target. Section 2 presented an example of this kind of *ex ante* research, conducted to detect the farmers' perceptions (Perceived Usefulness and Perceived Ease of Use) on a not-yet-existing technology, therefore no farmer had a usage experience with it. Simultaneously the same technology that was exactly the subject of the survey was developed (Section 3).

Information coming from the survey was meaningful not only for the first phase of development but also for the next steps until the adoption occurred: creating the conditions that stimulate farmers to search information about PA technologies, provide data to demonstrate the economical sustainability and, maybe the most important aspect, organize a technical support service. The review revealed, and then the survey confirmed, the strong importance of providing technical support to enable farmers to use the technology and to interpret data autonomously. Before launching a new technology, which is the expectation of potential users in terms of support must be already known.

Only at the end of this long process the farmer will have to decide whether or not to purchase a technology. The challenge is to arrive well prepared to that moment and my hope is that the present work could give some help in defining the way to do it.

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