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ΔΙΔΑΚΤΟΡΙΚΗ ΔΙΑΤΡΙΒΗ

Πληροφοριακό σύστημα διαχείρισης γεωργικού εξοπλισμού

ΖΗΣΗΣ Θ. ΤΣΙΡΟΠΟΥΛΟΣ

Πληροφοριακό σύστημα διαχείρισης γεωργικού εξοπλισμού

Farm Management Information System of Agricultural Equipment

ΤΡΙΜΕΛΗΣ ΣΥΜΒΟΥΛΕΥΤΙΚΗ ΕΠΙΤΡΟΠΗ			
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ΠΕΡΙΛΗΨΗ

Ζήσης Γ. Τσιρόπουλος, 2023. Πληροφοριακό σύστημα διαχείρισης γεωργικού εξοπλισμού,

Διδακτορική διατριβή, Πανεπιστήμιο Θεσσαλίας, Νέα Ιωνία, Βόλος, Ελλάδα

Η γεωργία είναι ένα πολυπαραγοντικό σύστημα, όπου διάφοροι παράγοντες επηρεάζουν τις καλλιέργειες και το τελικό αποτέλεσμα των αποδόσεων, του κόστους και του κέρδους για τον αγρότη. Μέχρι σήμερα, οι αγρότες βασίζονται στην εμπειρία τους για τη διαχείριση των αγροκτημάτων τους. Αυτό όμως πρέπει να αλλάξει καθώς ο τομέας της παραγωγής τροφίμων καλείται να αυξήσει μέσα στις επόμενες δεκαετίες την παραγωγή του έως και 70% προκειμένου να καλυφθούν οι μελλοντικές διατροφικές ανάγκες του πληθυσμού της γης, ο οποίος προβλέπεται να αυξηθεί στα 9.6 δισεκατομμύρια μέχρι το 2050. Επιπρόσθετα, η αλλαγή του κλίματος, ο ανταγωνισμός για τη χρήση γης, η υποβάθμιση των εδαφών και η ανάγκη μείωσης των αρνητικών επιπτώσεων στο περιβάλλον, θα ασκήσουν επιπλέον πίεση στην αγροτική παραγωγή και στον εφοδιασμό του πληθυσμού με τρόφιμα. Κάτω από αυτό το πρίσμα η υιοθέτηση Τεχνολογιών Γεωργίας Ακριβείας, οι οποίες σχετίζονται με την αποτελεσματικότερη εφαρμογή των εισροών (σπόροι, λιπάσματα, χημικά προϊόντα, νερό, καύσιμα, εργασία), την αυξημένη ταχύτητα εργασίας, τη μείωση των περιβαλλοντικών επιπτώσεων, καθώς και με τις καλύτερες αποδόσεις και ποιότητα των αγροτικών προϊόντων είναι μονόδρομος.

Σήμερα, οι τεχνολογικές καινοτομίες των συστημάτων παρακολούθησης της απόδοσης των γεωργικών ελκυστήρων επιτρέπουν την ανάκτηση της κατάστασης και των δεδομένων τους μέσω του ISOBUS (Διεθνής Οργανισμός Τυποποίησης, 1997) και παρέχουν χρήσιμες πληροφορίες για τη βελτιστοποίηση των εργασιών. Σε συνδυασμό με το Παγκόσμιο Δορυφορικό Σύστημα Πλοήγησης (GNSS), παρέχουν βελτιωμένη διαχείριση αγροκτημάτων και λειτουργιών μέσω της χρήσης εκτεταμένων βάσεων δεδομένων για την υποστήριξη των αποφάσεων. Επιπρόσθετα, βρισκόμαστε στο μέσο της 4ης Βιομηχανικής Επανάστασης (Industry 4.0 – IR4), όπου αναπτύσσονται και χρησιμοποιούνται σύγχρονες έξυπνες τεχνολογίες σε διάφορους τομείς, συμπεριλαμβανομένης της γεωργίας. Μέσω αυτών των τεχνολογιών, οι εν κινήσει αισθητήρες τοποθετημένοι σε γεωργικά μηχανήματα και επιτόπιοι αισθητήρες IoT παρέχουν αναλυτικές πληροφορίες για το έδαφος, τις καλλιέργειες και τις περιβαλλοντικές συνθήκες. Μέσω των υπαρχουσών τεχνολογιών, ο σημερινός παραγωγός έχει στη διάθεση του πάρα πολλές λύσεις, δεν μπορεί όμως να κατανοήσει την ακριβή κατάσταση

των καλλιεργειών του, όντας μπερδεμένος από τις πολλές και μη συνεργαζόμενες πηγές πληροφοριών που παρέχονται από διάφορα εργαλεία.

Παρόλο που η κατάσταση αυτή, μοιάζει να είναι αποτέλεσμα των ραγδαίων εξελίξεων των τελευταίων ετών στον τομέα της τεχνολογίας, η ανάγκη για συλλογή και ομαδοποίηση των δεδομένων μιας φάρμας είχε προβλεφθεί και μάλιστα αρκετά νωρίς. Το 1976 δημιουργήθηκε το πρώτο Σύστημα Διαχείρισης Γεωργικών Εκμεταλλεύσεων (FMIS – Farm Management Information System), το οποίο χρησιμοποιήθηκε από 10.000 Καναδούς αγρότες, για την καταγραφή και τον προγραμματισμό των γεωργικών εργασιών, ενώ το πρώτο FMIS με ενσωματωμένους αλγορίθμους υποστήριξης αποφάσεων παρουσιάστηκε το 1986. Την δεκαπενταετία 2000-2015 η τεράστια εξέλιξη στους υπολογιστές και η εισαγωγή των έξυπνων τηλεφώνων στην ζωή του καθημερινού πολίτη οδήγησε στην δημιουργία πολλών FMIS οικονομοτεχνικού χαρακτήρα , ενώ από το 2015 έως και σήμερα η δυνατότητα που έχει δοθεί για δωρεάν πρόσβαση σε δορυφορικά δεδομένα μεγάλης ανάλυσης, έχουν βοηθήσει στη δημιουργία αρκετών FMIS που μπορούν να παράγουν χάρτες με την κατάσταση των καλλιεργειών (π.χ. ευρωστία - NDVI), καθώς και χάρτες μεταβλητής δόσης (π.χ. λίπανση).

Όμως, 47 χρόνια μετά την πρώτη εμφάνιση των FMIS, και κάνοντας την αποτίμηση, μπορεί να αναφερθεί ότι η πρόοδος των FMIS δεν ακολούθησε σε ρυθμό τις τεχνολογικές εξελίξεις, με αποτέλεσμα να μην έχει δημιουργηθεί μέχρι στιγμής ένα FMIS ικανό να βοηθήσει πλήρως τους παραγωγούς στην διαχείριση των εκμεταλλεύσεων τους, καλύπτοντας κάθε πτυχή των καθημερινών καλλιεργητικών πρακτικών και φροντίδων που αυτοί επιτελούν.

Στα πλαίσια αυτά, στόχος της παρούσας διπλωματικής εργασίας ήταν η μελέτη της υπάρχουσας γνώσης για το FMIS και η ανάπτυξη ιδεών και εφαρμογών που μπορούν να συμπληρώσουν τα υπάρχοντα συστήματα και να καλύψουν τις απαιτήσεις των αγροτών. Μέσω της μελέτης αυτής, αναλύθηκε η παρούσα κατάσταση, ερευνήθηκαν οι μελλοντικές προοπτικές και εντοπίστηκαν οι ανάγκες των παραγώγων. Τα παραπάνω οδήγησαν στο σχεδιασμό και την υλοποίηση ενός πρωτοποριακού πληροφοριακού συστήματος διαχείρισης γεωργικού εξοπλισμού (Farm Machinery Management Information System – FMMIS), που στόχος του είναι να καλύπτει κάθε πτυχή των εργασιών ενός αγροκτήματος, σε επίπεδο υποστήριξης αποφάσεων, τεχνοοικονομικής ανάλυσης, και προβολής/ανάλυσης δεδομένων, ικανού να προσφέρει πλήρη αυτοματοποίηση ή υποβοήθηση των διάφορων καλλιεργητικών εργασιών.

Το FMMIS δοκιμάστηκε και επικυρώθηκε για την αποτελεσματικότητα του σε τρεις διαφορετικές περιπτώσεις χρήσης. Η πρώτη περίπτωση, ήταν η χωρική ανάλυση των δυνάμεων κατεργασίας του εδάφους για μείωση της κατανάλωσης καυσίμου και αυξημένη απόδοση της κατεργασίας, η δεύτερη ήταν η δημιουργία ενός αυτόνομου οχήματος για πραγματοποίηση γεωργικών εργασιών σε οπωρώνες και αμπελώνες, και η τρίτη ήταν ο σχεδιασμός και η δημιουργία ενός χαμηλού κόστους IoT κόμβου γεωργία ακριβείας.

Όλες οι υλοποιήσεις έγιναν με γνώμονα την Ελληνική πραγματικότητα. Ως αποτέλεσμα, όλα τα υλοποιούμενα χαρακτηριστικά του FMMIS, τόσο σε υλικό (υλισμικό) όσο και σε λογισμικό, αναπτύχθηκαν με τέτοιο τρόπο ώστε να ξεπεραστούν οι παράγοντες που ελαχιστοποιούν την υιοθέτηση νέων γεωργικών τεχνολογιών στην ελληνική αγροτική κοινότητα. Πιο συγκεκριμένα, κάθε υλοποίηση έχει χαμηλό κόστος απόκτησης και πολύ μικρό χρόνο απόσβεσης που οδηγεί νωρίς στην κερδοφορία, τα συστήματα είναι εύχρηστα εφαρμόζοντας φιλικές προς το χρήστη λειτουργίες. π.χ. plug and play μεθοδολογία για την ελαχιστοποίηση της πολυπλοκότητας και των αναγκών εκπαίδευσης, και παρέχουν υψηλή ακρίβεια και ευχρηστία κατά τη χρήση τους στο αγρόκτημα.

Επιπλέον, τα χαρακτηριστικά του FMMIS επικεντρώνονται στην ελαχιστοποίηση του κόστους των γεωργικών εργασιών, αντιμετωπίζοντας δύο προβλήματα που είναι κρίσιμα για την ελληνική αγροτική κοινότητα, δηλαδή το κόστος των καυσίμων και το κόστος της άρδευσης. Καθώς αυτά τα κόστη είναι αρκετά υψηλά, το FMMIS έχει τη δυνατότητα να μειώσει την κατανάλωσή τους σε αρκετά μεγάλο βαθμό, επιτυγχάνοντας μείωση κατανάλωσης καυσίμου έως 50% και μείωση κατανάλωσης αρδευτικού νερού έως 30%, καθιστώντας το FMMIS ένα εργαλείο που μπορεί να υιοθετηθεί εύκολα από τους Έλληνες αγρότες καθώς κατανοούν εύκολα τη χρησιμότητα της ελαχιστοποίησης αυτών των δαπανών. Τέλος, προτείνει τη χρήση μη επανδρωμένων οχημάτων χαμηλού κόστους που μπορούν να βοηθήσουν στον εκσυγχρονισμό του ελληνικού αγροτικού τομέα, στην περαιτέρω ελαχιστοποίηση του λειτουργικού κόστους και στη μείωση της εργασίας που απαιτείται για τη διαχείριση του αγροκτήματος, καθώς το ελληνικό αγροτικό δυναμικό ακολουθεί αρνητική τάση.

ABSTRACT

Agriculture is a very complex system, where various factors affect crops and the final outcome of yields, costs and profit for the farmer. Up until now, farmers used to rely on their experience for their farms’ management. However, this process is about to change as it is required of the food production sector to increase its production by up to 70% in the coming decades in order to meet the future nutritional needs of the world's population, which is projected to increase to 9.6 billion by 2050. Additionally, climate change, competition for land use, soil degradation and the need to reduce negative environmental impacts will put additional pressure on agricultural production and food supply. In this regard, the adoption of Precision Agriculture technologies, which are related to the more efficient application of inputs (seeds, fertilizers, chemicals, water, fuel, and labour), the increased speed of work, the reduction of environmental impacts, as well as the better yields and quality of agricultural products is a one-way street.

Today, technological innovations in agricultural tractor performance monitoring systems allow their status and data to be retrieved via the ISOBUS protocol (International Organization for Standardization, 1997) and provide useful information to optimize operations. Combined with the Global Navigation Satellite System (GNSS), they provide improved farm and operations management through the use of extensive databases to support decisions. Additionally, we are in the middle of the 4th Industrial Revolution (Industry 4.0 – IR4), where modern smart technologies are being developed and used in various sectors, including agriculture. Through these technologies, on-the-go sensors mounted on agricultural machinery and IoT field sensors provide detailed information about soil, crops and environmental conditions. Through existing technologies, today's farmers have many solutions at their disposal, but they cannot define the exact conditions of their crops, being confused by the plethora of information from uncooperative sources provided by various tools.

Although this situation seems to be a result of rapid technological development of recent years, the need for data collection and data categorisation of farms was already foreseen. In 1976, the first Farm Management Information System (FMIS) was created and used by 10,000 Canadian farmers to record and plan agricultural operations, while the first FMIS with integrated decision support algorithms was presented in 1986. Between 2000 and 2015, the huge development in computers and the introduction of smartphones in everyday life led to the creation of many FMISs with an economic and technical orientation, while from 2015 until today, free access to high resolution satellite data has helped towards the creation of several FMIS that can produce crop condition maps (e.g. robustness - NDVI) as well as variable rate maps (e.g. fertilization).

Regardless, 47 years after the first appearance and the assessment of FMIS, the fact is that the progress of FMISs has not kept pace with the overall technological development. Thus, no FMIS is capable of fully assisting farmers in every day operations.

In this context, the aim of this thesis was to study the existing knowledge about FMIS and to develop ideas and applications that can complement the existing systems and meet the demands of farmers. Through this study, the current situation was analysed, future prospects were investigated and farmers’ needs were identified. The aforementioned points led to the design and implementation of an innovative Farm Machinery Management Information System (Farm Machinery Management Information System - FMMIS), which aims to cover every aspect of a farm's operations, at the level of decision support, techno-economic analysis, and visualization/analysis of data, able to offer complete automation or assistance on various operations.

FMMIS was tested and validated for its effectiveness in three different use cases. The first case was the spatial analysis of tractor–implement draft forces for the reduction of fuel consumption and increase of tillage efficiency, the second was the creation of an autonomous vehicle for agricultural operations at orchards and vineyards, while the third was the design and creation of a low-cost precision agriculture Internet-of-Things (IoT) system.

Current conditions in Greece factored greatly in the implementation of all use cases. As a result, all the implemented features of the FMMIS, both hardware and software, were developed in such a way as to overcome the factors that minimize the adoption of new agricultural technologies in the Greek agricultural community. More specifically, each implementation has a low cost of purchase and a very short payback time that leads to early profitability, while the systems are easy to use by supporting user-friendly functions as plug and play methodology to minimize complexity and training needs, and provide high accuracy with increased usability.

In addition, the FMMIS features focus on minimizing the cost of agricultural operations, addressing two critical problems for the Greek farming community, namely fuel costs and irrigation costs. As these costs are quite high, the FMMIS has the potential to reduce the fuel and irrigation consumption to a considerable extent, achieving reduction in fuel consumption of up to 50% and reduction in irrigation water consumption of up to 30%, making the FMMIS a tool that can be easily adopted by the Greek farmers as they easily understand the importance of minimizing these costs. Finally, it proposes the use of low-cost unmanned vehicles that can help modernize the Greek agricultural sector, further minimize operating costs and reduce the labour required in farm management, as the Greek agricultural labour force follows a negative trend.

ΕΥΧΑΡΙΣΤΙΕΣ

Η παρούσα διατριβή εκπονήθηκε στο Εργαστήριο Γεωργικής Μηχανολογίας του Τμήματος Φυτικής Παραγωγής και Αγροτικού Περιβάλλοντος του Πανεπιστημίου Θεσσαλίας.

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1 Farm Management information systems

1.1 Background

Precision Agriculture (PA) has now a history of more than 30 years. Precision agriculture technologies have provided farmers the opportunity to cope with in-field variability and to handle and manage efficiently a vast amount of available information[1,2]. The last 30 years significant of efforts have been made for the development of new precision agriculture/smart farming technologies and for increasing the adoption by the farmers. As these technologies can contribute to the sustainability of the agricultural sector, by meeting the increasing demand for food, the environmental sustainability and food security, the adoption seems a necessity. This necessity is well known for years to the policymakers. For example, EU's strategic research within Horizon 2020 mentioned digital agriculture as one of the ten (10) emerging trends in digital technology and innovation[3]. To this extend, EU's 2020 strategic report[4] splits the emerging trends/dimensions into four (4) sectors, namely, the social and economic dimension, the geopolitical dimension, the green dimension and the digital dimension. One of them is the green dimension where agriculture plays a dominant role. Another sector is the digital dimension where the Green ICT is one of the main case studies. Even COVID19 crisis reinforced the need of using PA, as the crisis helped on speeding up the digital transformation even in everyday life[5], and the general public is now more concerned regarding the negative impact of human activities to the environment[6].

Nowadays, we are in the middle of 4th Industrial revolution (Industry 4.0 – IR4), where modern smart technologies are developed and used in the various sectors including agriculture. In total it is considered that 9 different technologies are driving IR4[7]. These are: Additive Manufacturing, Augmented Reality, Autonomous Robots, Big Data and Analytics, The Cloud, Cybersecurity, Horizontal and Vertical System Integration, The Industrial Internet of Things and Simulation From these technologies, the most promising for agriculture domain are: the Internet of Things (IoT), the cloud, the big data and their analytics or analysis.

Following IR4 revolution, the technological innovations of on-board tractor performance monitoring systems and the advances in tractor's technology enables the acquisition of tractor and implement status and data through the ISOBUS (International Organization for Standardization, 1997)[8], and provide useful information to optimize the overall field productivity[9,10]. Combined with the Global Navigation Satellite System (GNSS), the system could be used for spatial mapping of agricultural operations[11,12] and for recording other farm data as tractor-implement field performance[13,14]. GNSS technologies emerge as standard features on contemporary tractors and provide enhanced farm and operations management through the use of extensive databases as the basis for decision support and control actions. Meanwhile, on-the-go sensors mounted on agricultural machinery[15] and on-site IoT sensors[16] provide site-specific analytical information of soil, crop and environmental conditions.

Furthermore, the development of autonomous vehicles adopted to various field tasks[17], will gradually downgrade the role of the tractor operator and will require an explicit management system capable of managing interactive information flows and provide useful guidelines in real-time for operations execution. The interconnection between the ISOBUS and precision agriculture innovations, as well as 4th Industrial revolution technologies will meet the farm manager's demands by open up a wealth of information for better management of crop production. The future agricultural tools have to be compliant with technological advances and enable the establishment of interrelationships between farm machinery, agricultural landscape (e.g. soil, water) and their surroundings (e.g. environmental impact, public entities, documentation of quality and growing conditions).

Nowadays the data that can be retrieved using the aforementioned technologies, as well as their potential sources are shown in **Table 1**.

Table 1: Types of agricultural data

Type of Data	Main measurements	Source of data
Weather Data	○ Temperature ○ Humidity ○ Precipitation ○ Solar Radiation (Light Intensity) ○ Wind Speed	○ In situ weather stations ○ Weather services
Weather Forecast	○ Temperature ○ Humidity ○ Rainfall	○ Weather services
Soil Data	○ Soil moisture ○ Soil temperature	○ In situ soil sensors

	o Conductivity o pH	o Remote sensing with satellite or aerial data (for some measurements) o Instruments (e.g. Conductivity)
Crop Data	o NDVI o Crop stage o Leaf wetness o Yield monitor o Quality measurements (size, brix)	o In situ sensors (e.g. Leaf wetness) o Instruments (e.g. NDVI) o Remote sensing with satellite or aerial data (for some measurements) o Remote sensing with cameras (normally attached at tractors or at Unmanned vehicles)
Location Data	o Routing o Positioning (e.g. sampling points) o Mapping (in combination with other data sources)	o Locations services (GNSS)
Field operations data	o Application quantity (e.g. fertilizer quantity) o Energy consumption (tractor, pumps)	o On board sensors at agricultural machineries and tractors (ISOBUS) o In situ sensors (e.g. Energy meters)
Data from soil or crop sampling (manual data)	o Soil analysis o Yield calculation (fruit and vegetable sectors) o Crop quality measurements	o Laboratory measurements o In situ measurement (using manual methods)
Actuation data	o Water flow Valves state o Actuator state	o In situ sensors o Actuators feedback o On board sensors and actuators on agricultural machineries, tractors and UV's

Currently, the managerial tasks for agriculture are transforming into a new paradigm, requiring more attention on the interaction between all farm aspects. The farm management systems have to be able to comply with legal regulations, agricultural production standards to ensure food safety and environmental protection. Compliance with additional quality requirements usually gives an added value in the market to the products. The rules and standards must be represented in a form understood by a computerised management system which will perform automated compliance checking. With that in mind, Nash et al.[18] suggested a general structural model for an agricultural standard that has to meet four criteria: 1) a machine-readable form of rule encoding 2) rules that are computable and correctly 'understood' by the software concepts 3) production of a discrete outcome for each rule which can be determined by a computer and 4) access of required data inputs in digital forms. AgroXML was a try to standardize the data format for information flows in agriculture domain[19]. On a further note, Nash et al.[20] propose an XML-based format for the formal representation of the rules and standards to enable the automation of compliance checking, while additional standards were developed for data exchange in agricultural environment (e.g. AgGateway, AgroEDI)[21].

The digitised information should be combined with the ‘‘farmer’s tacit knowledge’’, building thus a real cognitive system[22]. According to Kitchen[23], an information-to-action decision process needs to be: (1) in situ sensor-based; (2) automated for real-time or near real-time computer processing and transformation into knowledge for decision making (3) packaged so that sensing and processing of information are a part of the equipment used to accomplish the required management action; and (4) transparent to the operator/manager for decision evaluation and confirmation. The data must be available in digital form to provide automated compliance assessment with common agricultural management standards[24]. Sørensen et al.[25] proposed the concept of Service Oriented Architecture (SOA) which contains an automated monitoring system of data collection and processing using a distributed approach, specifically web-services.

Information to-action decision processes as well as precision agriculture applications require sensors for on-the-go data collection of crop and soil variability (e.g. soil moisture content, NDVI, crop density etc). The ISOBUS protocol plays an important role in the development of precision agriculture and helps information to be exchanged and stored more efficiently between sensors, processors, controllers and software packages from different manufacturers within the same tractor and/or vehicle[26]. The challenge is to integrate the data of these new technologies into a coherent farm management system. The main problem arises from the heterogeneous nature of these data resulting in a variety of data formats and interfaces. Incompatibility of different data formats are usually a fundamental problem and considerably manual efforts is required just to convert data from one format to another. Therefore, there is an imperative need for continuous data exchange either between the farm’s computer and the computing devices mounted on the farm machinery or between the farm’s computer and the external farming systems such as contractors, suppliers and advisory services, etc.

Nowadays, ISOBUS is considered as a standard within the agricultural industry and consisting of fourteen parts (such as data link layer, network layer, task controller and management information system data interchange), providing functionalities and other targeted options to developers. The ISOBUS data can also be merged with GNSS information to support spatial analysis of machinery systems. Steinberger et al.[27] presented a prototype implementation of an agricultural process-data service that enables flexible data networking based on the farming standard without much complexity for the farmers/farm managers. The data are recorded through the ISOBUS port and transferred to a server where data is analyzed and aggregated to completed jobs and can be requested for further use via a web portal and a web service interface.

In farming businesses however, data exchange requirements are not fixed and changes occur frequently. The data exchange techniques usually lack flexibility with regards to management of efficient requirement changes and the system often needs manual maintenance. The low-level hand held data conversion from one format to another usually requires a lot of manual work, which causes problems and is much confusing for ordinary farmers. Iftikhar and Pedersen[28] proposed an easy-to-use and flexible solution for ISOBUS based bi-directional data exchange as well as efficient requirements change management. The system utilizes an XML-based graphical user interface generating high-level data exchange specifications that can be simply used by farmers/farm managers. The solution work well in low-bandwidth and partially disconnected environments, and where the data exchange requirements are not fixed and changes occur frequently, as in the farming business. The authors also point out the future need to implement a rule-based tool for bi-directional exchange of data that will provide the underlying rules of an interactive procedure for generating high-level data exchange specifications with ease-of-use. Some kind of automation on the management of the farms may be also required[29]. The system must be context aware and act autonomously when a situation arises that need corrective actions. Under this perspective, new sensors and capabilities are constantly added into ISOBUS protocol for increasing its operability[30,31].

Raimo Nikkilä et al.[32] evaluated a web-based approach for the implementation of a system that fulfils the requirements posed by precision agriculture. As mentioned above, these new requirements must have increased connectivity capabilities with external services targeting precision agriculture and GIS/GNSS data. Also, the communication with the ISOBUS-tractor-implement combination that carries out the field operations are fundamental in scope. Furthermore, Kaloxylos et al.[33] point out that current configurations face shortcomings especially in handling vast numbers of networked devices. There is still no standardized solution to enable a simple and cohesive interoperability among services and stakeholders. It was argued to introduce autonomic and cognitive elements in the overall management process to support and integrate different stakeholders and services, interworking with the networked infra-structures. Finally, an intelligent system must receive data from the user in a friendly manner and store it in a correct format in a programming language that has inferencing capabilities to include rules that will prevent the entry of contradictory data, numbers that are out of range and inconsistent information[34].

1.2 Introduction to Farm Management Information Systems

The tremendous progress on technological advances in computers and electronics in agriculture in the last decades has brought significant changes in working environment for the farming community. This has generated a vast amount of data to be used by farmers and the challenge is the best exploitation of these data to make useful and practical information available for crop production. The farm manager of today has to choose among different vendors of technologies and data providers to use the most appropriate information to make the best decisions for his or her farm.

Decision making is a crucial component for the farmers and many researchers have studied it in relation to the availability of providing data[35,36]. The most important aspect of carrying out research in farm management decisions is to understand the tacit knowledge of farmers, and how farmers react when a decision should be made[37]. This is the most important direction that researchers working with data management in agriculture should pursue to provide farmers with the information they need to enhance decision making at specific stages of their production process.

The basis for efficient decision making is availability of high-quality data. In Europe, most of the farms are having difficulties in using the available data and information sources, which are fragmented, dispersed, difficult and time-consuming to use. This indicates that the full potential of these data and information are not well utilized by farmers. The integration of historical data, real-time data from various farming sources, knowledge sources, compliance to standards, environmental guidelines and economic models into a coherent management information system is expected to remedy this situation[38].

Farm management information systems (FMIS) have advanced from simple farm record-keeping systems to large and complex systems in response to the need for communication and data transfer between databases to meet the requirements of different stakeholders. The FMIS are electronic tools for data collection and processing to provide information of potential value in making management decisions[39]. They exist when main decision makers use information provided by a farm record system to support their business decision making[40]. In a more detailed expression, FMIS is defined as a planned system for collecting, processing, storing and disseminating data in the form needed to carry out farm operations and functions[41].

The first introduction of FMIS was occurred in 1970’s where the applications were record keeping and operations planning (Blackie, 1976[42]; Thompson, 1976[43]). Canfarm was the first application used by Canadian farmers, where 10,000 farmers were using it for record keeping and 4,000 for planning in 1978 (Thompson, 1976[44]). FMIS with incorporated decision support algorithms into recording keeping and planning were presented by Kok and Gauthier[45]. It consisted of four major components: permanent data that are seldom changing; annual data that can be linked to a particular cropping season or administrative year; daily data representing daily farm operations; and inventory data related to farm stocks and suppliers. This type of design and architecture is quite common in the many current commercial applications. CALEX system was the first application documented that combined record keeping, planning and decision support tools for specific far operations, mainly pest management, irrigation and fertilization[46].

To improve the functionality of the FMIS, a number of software architectures and designs have been introduced over the years including increased levels of sophistication using web-based applications and emerging technologies in agricultural production (e.g., precision agriculture, automated data transfer). Web-based services facilitate collaborative research over the Internet connecting geographically dispersed teams to work[47], such as farmers and crop advisors or personalizing the data by the end user for adapted analysis or presentation purposes[48], as well as standard language for data exchange between systems and services based on XML and JSON APIs, and a service bus as a message-oriented middleware for connection of Web Services[49].

The majority of the farm management information and decision support systems described in the scientific literature are based on simulation models or targeted optimization models and methods sometimes in combination with probabilistic methods. The included methodologies like Linear Programming[50], Dynamic Programming[51], Rule-based Management[52], Decision Trees[53], Expert Heuristics[54], Fuzzy Optimization[55], Generic Algorithms[56] and Smart Elements[57] to model, solve, and generate optimal strategies.

As agriculture is characterized by a high degree of uncertainty, a deterministic, as a backbone of a FMIS model cannot fully capture the probabilistic nature inherent in agricultural production systems. However, few FMIS deal with uncertainty in farm management problems[58,59,60], while most consider only deterministic aspects[61,62]. Uncertainty assessment is the less understood and implemented capability of farm management and decision support systems. It estimates the probability of recommended alternatives, by placing confidence intervals on the most likely outcomes, or quantifying the likelihood of exceeding some environmental thresholds. It also conducts risk assessments based on probabilities of unfavourable outcomes[63].

A number of FMIS designs and architecture, mostly conceptual, have recently been developed related to machinery management, mainly due to the increasing number of data generated by the tractors, with the standard inclusion of the ISOBUS protocol for tractors and implements. Finally, holistic FMIS have been recently presented to capture all data flows by the various actors linked with FMIS. According to Sørensen et al[64], a FMIS is needed to advise managers of formal instructions, recommended guidelines and documentation requirements for various decision making processes. They presented an architecture having the farmer as the central decision maker as related to planning, controlling and operating a crop production system indicating on how the operational field data needs to be collected and transformed in an automated way. To cover all activities from planning, to execution and evaluation activities, a reference architecture design has been presented[65], identifying the actors involved, their roles and communication specifics related to decision and control processes.

1.3 FMIS for precision agriculture (PA)

The introduction of precision agriculture technologies into common farm activities has brought farmers the opportunity to cope with in-field variability along with the great challenge to handle and manage properly a vast amount of available information. Meanwhile, environmental restrictions, food safety, globalization of trade markets and changes in consumer demands have made management of farms a highly complex task.

The advent of Precision Agriculture (PA) information technologies and electronic communication along with the development of more accurate Global Navigation Satellite Systems (McCown) at reasonable costs have enabled farmers to acquire large amounts of data in the field to use effectively in site-specific crop management. Early FMIS, however, operated largely in an non-spatial realm, using computer simulation models to project current conditions into alternative future scenarios[66,67,68]. In that context, precision and accuracy were insufficient requiring the development of spatial management features. **Figure 1** shows a conceptual outline of the spatial management of field operations involving the acquisition of spatial and temporal data and the subsequent processing and inference within the realm of a FMIS for final decision support on operations management and activity documentation aimed at external stakeholders.

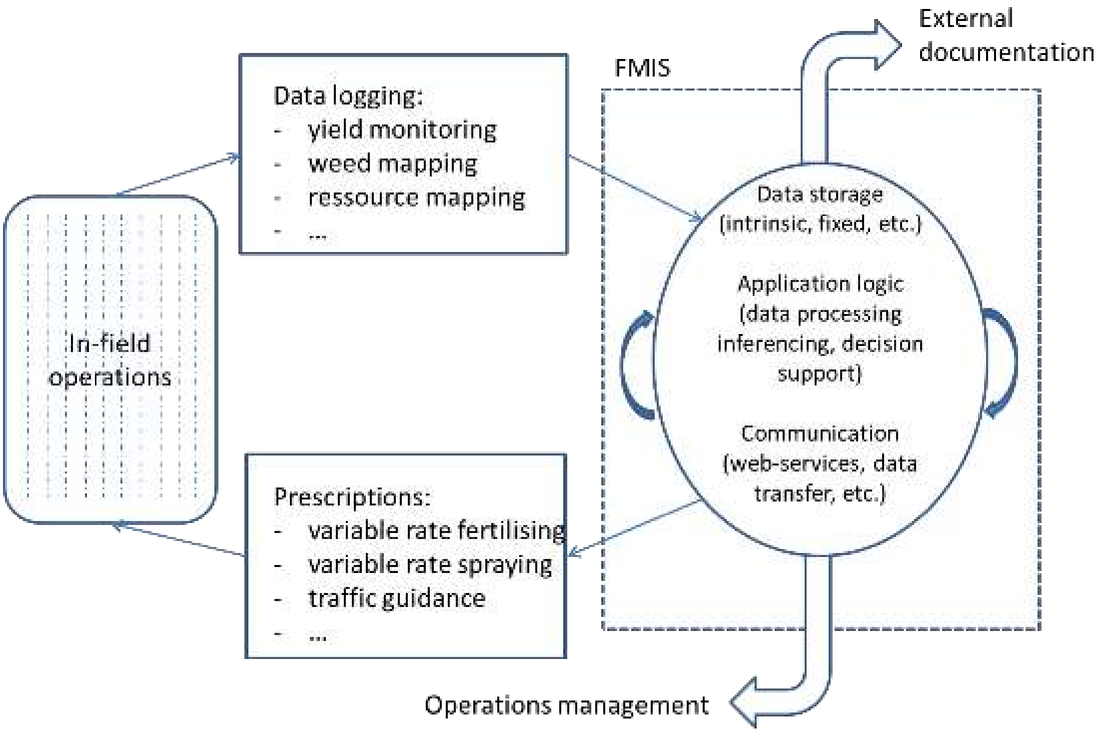


Figure 1: Conceptual outline of Precision Farming induced FMIS

This development aimed at supporting decision processes with inherent decisive spatial requirements. The employed methods include dynamic spatial links that allow the simulation at one location to impact other locations at each time step. This functionality is essential for whole farm management, because individual parts of the farm often share or transfer resources.

Due to the increasing data generation from precision agricultural applications, Fountas et al.[69] defined the information flows for the decision making on precision agriculture and Nikkila et al.[70] defined the requirements needed to make up the architecture of a FMIS for precision agriculture, which compared to a traditional FMIS, is more focused on the digital transfer of data and storing, managing and handling of GIS data, since most of the calculated data originates from external sources. The formulation of the operational plans and the ability to manage several transformations of the acquired data in order to achieve interoperability with all relevant systems and services is also required by a FMIS for precision agriculture. In the same line, Nash et al.[71], analysed the data flows within precision agriculture operations. The basic idea was to capture the different planning levels and control activities, which take place in a targeted production system and represent explicitly the domain knowledge in terms of domain entities and their relationships. This study presents the inherent vast amount of data generated by using precision agriculture and the complex interrelationships between the different activities.

The development of FMIS is growing rapidly in order to produce new and useful tools for the agricultural community to meet the demands from the markets. A study by the Wageningen University, aimed at presenting the current situation of FMIS and the use of data standards, provided an overview of all the functionalities used and data standards offered by applications in the market through the creation of a reference model[72]. Key points included the importance of common data exchange between the FMIS and external actors, such as agricultural inputs suppliers, processors, data providers, and governmental offices.

Moreover, the wide use of internet has brought new possibilities and challenges, namely to fulfil the increasing needs of farmers and agricultural advisers for time critical up-to-date and precise information as part of farm management. Web and mobile applications, created by expert systems, support data collection from different sources and integrate the results into personalised web graphical user interface (Web GUI) with embedded graphics, expert interpretations and links[73] [74] [75] [76]. Moreover, and the introduction of IoT along with the later advances in cloud computing and hardware and software capabilities of mobile phones has made feasible real-time data recording and fuelled the interest for ‘on the go’ information in the field[77] [78] [79] [80]. Web and mobile applications prove to be a very powerful tool particularly for the less experienced users.

1.4 FMIS adoption and profitability

Alongside the actual physical development of FMIS and the early introduction of computers on the farms, user requirements and adoption studies for FMIS were initiated. Sonka[81] argued that the change from rigid and inflexible management strategies to the flexible and adaptable management of the information stage, the potential contribution of the farm computers and systems would be significantly enhanced. Doluschitz and Schmisseur (1988)[82] predicted that Decision Support Systems (DSS) and expert systems in agriculture as integrated parts of an FMIS would have a vast influence as resolving analytical shortcomings of the end user (farmer) by transforming raw data through analysis and expert interpretation into useful information. On the other hand, Ohlmer[83] stated that farmers tend to use FMIS for executing similar management tasks and knowledge generation as previously supported by hired service organizations or advisors, indicating that the farm management methods have not been sufficiently matured in the introduced computer software systems. In summary, FMIS adoption rely not only on pure technical aspects but also to a high degree on the human or usability aspects of information systems implementation[84].

Kuhlmann and Brodersen[85] argued that commercial software products have reached a level of sophistication involving complex algorithms that can address demanding planning problems. However, such complex systems present a challenge in terms of acceptability and usability, making farmers revert to use ad-hoc calculations using, for example, standard spread sheet software. They noted that with the advent of new technologies like precision agriculture, the amount of data collected is by all degree too large to be managed by simple spread sheet software making the case for a wider adoption of more sophisticated FMIS for crop production.

A farmers' adoption study by Lawson et al.[86], pointed out that there are benefits for introducing advanced FMIS in relation to budgeting procedures, field planning and paperwork for subsidy applications and public authorities. They compared the FMIS adoption among Northern and Southern EU countries and they found that that Northern European farmers are keener on spending more time on working with computers than their Southern counterparts, probably due to the most developed and more business oriented type of farms that exist in Northern Europe.

A key point in FMIS development and adoption is the profitability of the employed system[87]. Profitability indicators are important not only to farmers who consider software investments, but also to developers that design and market FMIS. The benefit from using a FMIS extends from the value of the improved decision making which, however, often is difficult to quantify. For example, the benefit from using a FMIS might depend on the actual level of experience of the user. As a special case, Lewis[88] added that younger farmers with relative lack of farming experience will particularly benefit from using a FMIS. Moreover, Steffe[89] argued that the cost for designing and setting-up an information system is relatively high stressing the need for the design of a dynamic and adaptable model to meet both current and future demands. Also, Steffe presented the benefits of integrating the data related to precision agriculture into a general FMIS, as it would automatically generate documentation data reducing management task times as well as better management quality in terms of providing regulatory bodies or accountants with precise information otherwise not available.

1.5 Farm Machinery Management Information System (FMMIS)

To sum up, FMIS architectures haven been proposed to cover a range of farm activities and functions. The main focus has been the farm manager as the main decision maker and main actor within the farm activities. FMIS tend to cover very complex systems with all possible interrelationships of data gathering in the farm, which reveals the complexity and the need for more holistic approaches. Apart from the target around the farm manager, recent FMIS architectures have been presented towards machinery management and also farm business activities.

Raimo Nikkilä et al.[90] evaluated a web-based approach to the implementation of an FMIS that fulfils the new requirements posed by precision agriculture. As mentioned above, these new requirements are increased connectivity with the external services of precision agriculture and the management of GIS data. Good communication with the ISOBUS tractor-implement combination that carries out the field operations are also fundamental. Farm data are stored off-site, on a well-backed-up central system, via the Web service where they are considerably more secure than on a volatile local farm PC. The authors also agree that special care must be given in the design of user interfaces as poor interfaces have been often identified as important reasons for low adoption of FMIS in agriculture. Furthermore, Kaloxylos et al.[91] point out that the Web network at present faces a number of shortcomings especially in handling vast numbers of networked devices. There is still no standardized solution to enable a simple and cohesive interoperability among services and stakeholders. The authors propose the introduction of autonomic and cognitive elements in the overall management process to support and integrate different stakeholders and services, interworking with the networked infra-structures. An intelligent information management system has also to be able to receive data from the user in a friendly manner and store it in a correct format in a programming language that has inferencing capabilities to include rules that will prevent the entry of contradictory data, numbers that are out of range and inconsistent information[92].

Moving from a static architecture that relies on intelligence and knowledge provided exclusive by agricultural specialists, into a dynamic cognitive functional system that allows the outcomes of each farming related data and corresponding farm management actions to be recorded and further analyzed in real-time to produce new rules, is essential for enhancing and improving agriculture's innovations functionality. Sorensen et al[93] has presented a user-centric approach to explicit model the information flows for targeted field operations. The information models are centered on the farmer/farm manager as the principal decision maker and involve external entities as well as mobile unit entities as the main information producers. By shifting the perspective from the farmer/farm manager as the core of the system to a tractor-sensors-centric approach will lead to a targeted innovative architecture where the information flows derive from an intelligent machinery entity that has an upgraded role as related to the decision making process.

The overall objective of this thesis was to develop a Farm Machinery Management Information System (FMMIS), by:

- reviewing commercial FMIS applications for the current situation and future perspectives by incorporating them into the FMMIS,
- creating a basic outline and structure for a FMMIS,
- investigating the factors affecting FMIS and PA tools adoption in order the FMMIS to be adopted from the farming community,
- developing the FMMIS structure, and
- testing the FMMIS in different use cases.

Reviewing of commercial FMIS applications was done for evaluating current FMIS designs and solutions available for farm businesses in the market in order to extract future needs and correspondence with current developments.

The creation of a basic outline and structure for a FMMIS was achieved using the soft system methodology (SSM). This approach enable the establishment of the interrelationships between farm machinery collected data and their surroundings, which guide into analysing the information flows, defining the databases to be used, knowledge encoding and the requirements for advanced FMMIS.

The investigation of the factors affecting FMIS and PA tools adoption was made for answering the question how the FMMIS and the new IR4 technologies capabilities can help on increasing PA adoption into farming community.

The FMMIS was developed using the results of the aforementioned action points by incorporating all the necessary tools and capabilities for providing a holistic dynamic FMMIS, which can be used from farming community for efficiently managing all farm aspects.

The testing of FMMIS in different use cases, showcases the FMMIS operability, using all the central elements of a FMMIS namely: tractor, autonomous vehicles and IoT technologies. More specifically the following systems were developed:

- An ISOBUS 3D Dynamometer for spatial analysis of tractor–implement draft forces for reduced fuel consumption and increased tillage efficiency,

- An Unmanned Ground Vehicle (UGV) for agricultural operations at orchards and vineyards,
- A low cost IoT node for Precision Agriculture Applications.

All the developed systems were tested and evaluated for their efficiency in helping farmers on managing their everyday activities and for minimizing agricultural inputs, contributing on the social need for a more environmental friendly agriculture.

2 Materials and methods

2.1 Review of commercial FMIS applications

This overview of FMIS was based on a desk study of available FMIS, which are used for multiple applications within the agricultural chain.

2.1.1 Selection of FMIS commercial applications and analysis procedure

The FMIS market is very large covering many cropping systems and the research was targeted according to two specific selection criteria. The first criterion narrowed the research to only cover crop production and, more specifically, open-field crops, since available solutions for greenhouses involve a very different concept incorporating many control algorithms. The second criterion targeted only solutions that identify the farm manager as the main user related to field operations and does not cover solutions related to Enterprise Resource Planning (ERP) operations.

The selected FMIS were focused on crop production and were centered on the farm manager as the primary user. Initially, to find relevant commercial applications, international FMIS vendors using English as the main language were selected. This allowed collecting data from United Kingdom, United States, Canada and Australia, as well as from other global software houses which provide their applications in English and have an English-based website. Then, the research encompassed also FMIS from the major European countries, namely Italy, Germany and France to a large extent cover the European agricultural software market. The data were retrieved through a structured approach: First, a web search using different keywords (e.g. farm management, farm software, agricultural management) was ran to create an initial group of applications; secondly, web portals dedicated to farmers were checked; and finally, group of applications were validated. The information retrieved from the software developers was analyzed using software demo versions when available. In 22 cases, the information provided from the website about the functions was ambiguous. Therefore, phone calls were made to the software vendors to collect the necessary information from a sale representative or technician. In total, 141 commercial FMIS from 75 different software vendors were analyzed according to services they offer to their respective users. The selected software applications were computer based (i.e. enabling farmers to organize work from the farm office) and supported web-based and mobile applications.

Eleven generic functions were determined as the main functions or services that the commercial FMIS offer to the farm managers (**Table 2**). The identification of these functions was mainly based on the guidelines provided by Robbemond and Kruize (2011), analysing the different applications and the functions that commercial applications offer together with data exchange protocols. Additionally, the selection was also based on recommendations by Abt et al. (2006) who anticipated that agricultural software should include production planning, production process integration, performance management, quality and environmental resource management, project management, sales order and contract management, enterprise asset management and human capital management.

Table 2: Main functions or services that the commercial FMIS offer to the farm managers

Function title	Function description
Field Operation Management	Includes the recording of farm activities. This function also helps the farmer to optimize crop production by planning future activities and observing the progress of the previously planned tasks. Furthermore, preventive measures may be initiated based on the monitored data.
Best Practice (included yield estimation)	Includes the invoking of production tasks and methods as related to applying the best practice according to agricultural standards (Organic standards, Integrated Crop management requirements). An estimate of yield is feasible through the comparison of actual demands and alternative possibilities, if hypothetical scenarios of best practices occurred.
Finance	Includes the estimation of the cost of every farm activity, input – outputs calculations, labour requirements, etc., per unit area. A comparison between projected and actual costs is also produced that feed into the final evaluation of the farm’s economic viability.
Inventory	Includes the monitoring and management of all the production materials, equipment, chemicals, fertilizers, seeding and planting materials. In this way, the quantity of

	the products is adjusted according to the farmer plans and the customer orders. The record of the traceability information is also an important feature of this function.
Traceability	Includes crop recall, using an ID labelling system to control the produce of each production section. Traceability records related to use of materials, employees and equipment can be easily archived for a rapid recall.
Reporting	Includes in general the creation of farming reports, like planning and management, progress of work, work sheets and instructions, purchased orders, cost reporting, plant information, etc.
Site specific	Includes the mapping of the features of the field. The analysis of the collected data can be used as guide for applying the inputs with variable rates. The goal of this function is to reduce or optimise inputs and to increase output.
Sales	Includes the management of orders from quote, the packing management and accounting systems and the transfer of expenses between the enterprises, the charge for services and the costing system for labour, supplies and equipment charge out.
Machinery Management	Includes the detailing of the equipment usage the average cost of every working hour or per unit area. Also, it includes the fleet management and the logistics.
Human Resource Management	Includes the employee management including, for example, the availability of employees in time and space. The goal is a fast and structures handling of issues which concern the

	employees such as work time, payment, qualification, training, performance and expertise.
Quality Assurance	Includes the process monitoring and evaluation of the production according to the current legislation standards.

Since each software house offers different products that can be combined in a single integrated solution, the analysis targeted at the functions covered by the complete solutions, performing a clustering analysis. Clustering methods are a family of multivariate data analysis techniques that allow to identify groups of objects that are similar to each other but different from objects in other groups[94]. The initial group of 141 FMIS resulted in 73 complete solutions. The clustering algorithm was selected with the aim of maximizing the difference between clusters to characterize them.

Although hierarchical clustering is one of the most common methods, it has some limitations for categorical data. Therefore, the two-step clustering approach was proposed to overcome the limitation of hierarchical clustering[95]. The first step is devoted to scan the data and define pre-clusters: every record is scanned deciding if it should belong to an existing pre-cluster or it originates a new one. SPSS implements an algorithm similar to the procedure suggested by Zhang et al.[96]. The main difference is that in SPSS categorical data can be handled.

In the second step, the pre-clusters created in the first step are grouped in the desired number of clusters. Since the two-step clustering is influenced by the order of data, many test had been conducted to determine the optimal number of clusters. The best results had been obtained with 4 clusters. There were tests for the validity of data, controlling for changes in cluster assignments as suggest by Hair[97]: less than the 15% of records change the cluster assignment, generating a stable solution. Finally specific attention was devoted in profiling the final solution. To conduct a clustering interpretation phase, specific attention was given to the agricultural practice. Faunally, two rounds of discussions with experts was held for defining a meaningful interpretation of the results, assigning names to clusters, and commenting on the function that are covered by each of them in comparison with the others.

2.1.2 Commercial FMIS analysis results

The analysis of the different FMIS applications turned up significant differences as expected based on the farmers' needs and the field management techniques differing from country to country. In **Figure 2**, the origin of the studied applications is presented. According to the results, USA develops 45% of the commercial FMIS applications, the European Union 37%, while there is a small contribution from farm vendors in other countries. The high number of commercial FMIS applications developed in the western world is probably caused by the heavily controlled and regulated agriculture not so evident in other parts of the world, even though this is changing due to globalization and international market requirements. Also, it is expected that western world farmers are more willing to adopt to such innovations as a result of age and education level. Potential applications in the fast growing countries, such as China, Brazil have not been included in this analysis.

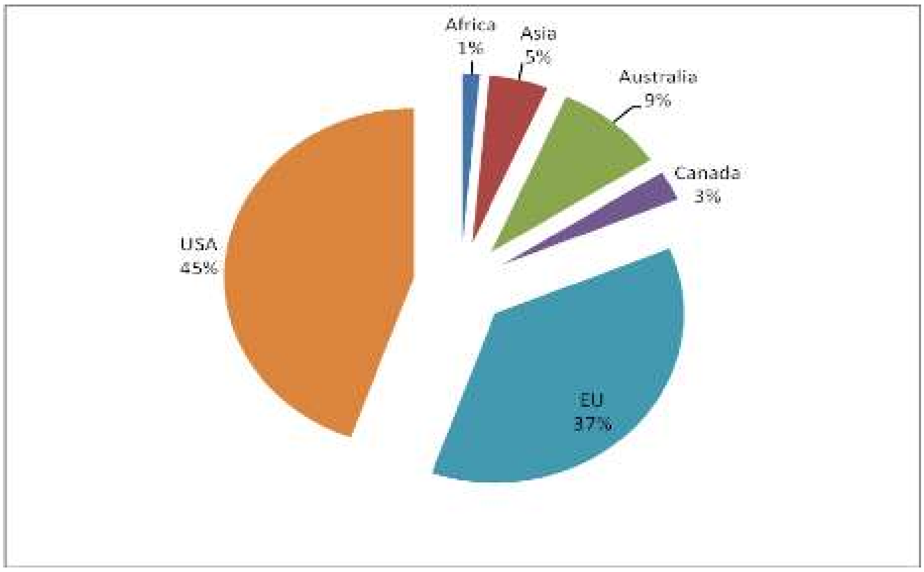


Figure 2: The origin of the studied FMIS applications

Figure 3 illustrates the occurrence distribution of the eleven FMIS functions. This allocation presents how frequently these functions appear in the vendors representing actually what are the most useful functions to the farmers. The functions most found in the software applications were field operation management (63%), reporting (57%), finance (45%), site specific management (40%), inventory (38%), machinery management (28%), and human resources (25%). Additionally, the less functions used were traceability (19%), quality assurance (19%). sales (18%) and best practice (16%).

It is obvious that the functions which contribute to the operation management and the economics of the farm enterprises are used more frequently together with reporting as an integral element of a FMIS. The high utilization rate of the site specific functions, though, reveals the farmers' willingness to implement precision agriculture techniques relating to the idea of rational use of inputs for both reducing production costs and environmental protection. This analysis also clearly demonstrated that traceability is still in its infancy for commercial FMIS, as well as the best practice functions, which are directly related to food quality and could be used to differentiate and value-enhance the farm's products as well as improve competitiveness[98]. Moreover, sales components within FMIS for farmers are still very limited, as usually farmers are not selling directly to end users. However, one of the strategies of the EU Directorate-General for Agriculture and Rural Development through the new Common Agricultural Policy is to facilitate direct sales between farmers and consumers and therefore more FMIS solutions in this domain may be introduced in coming years.

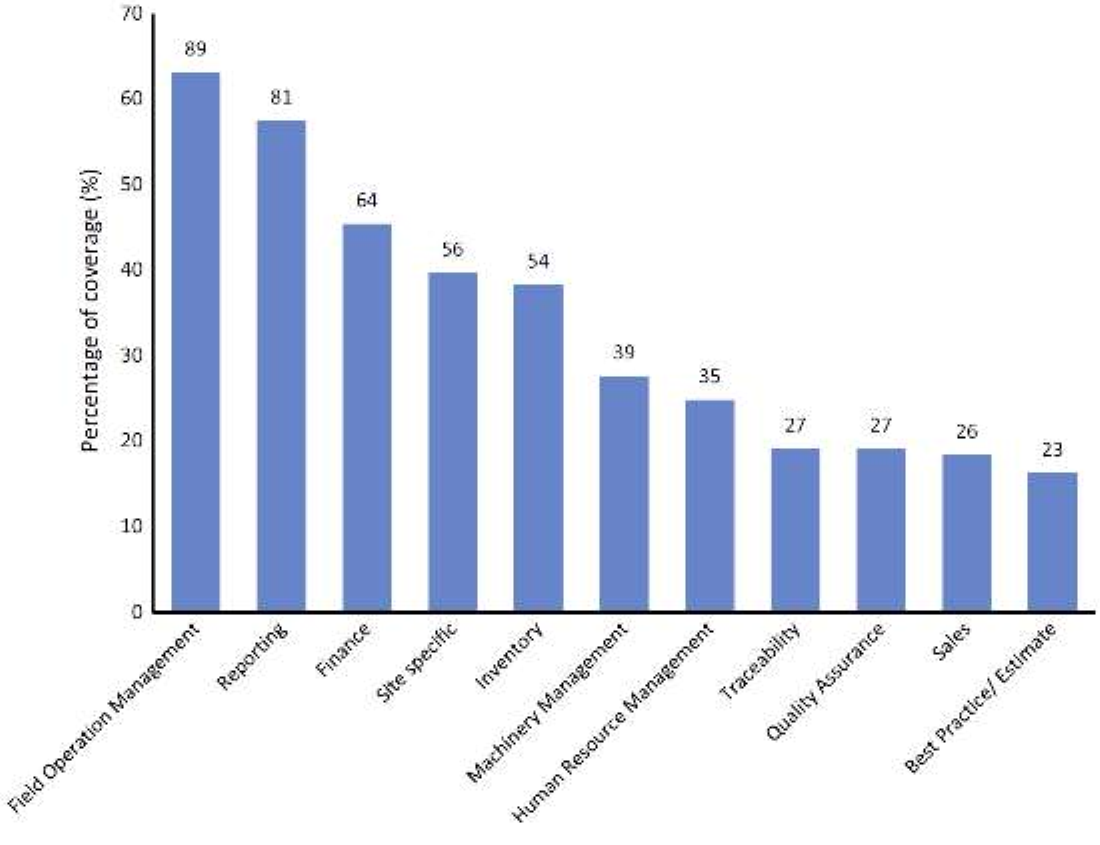


Figure 3: The occurrence distribution of defined functions in the studied FMIS

2.1.3 Clustering analysis results

The clustering analysis conducted on the full-solutions allowed to identify four different clusters, which differentiate along the 11 functions previously listed. This paragraph, is referring to FMIS as complete packages resulting from the combination of all the compatible modules offered by a software house in a single solution. **Figure 4** reports the results of the cluster analysis, showing on the y-axis the percentage of systems that cover a specific function and **Figure 5** shows the four resulted clusters.

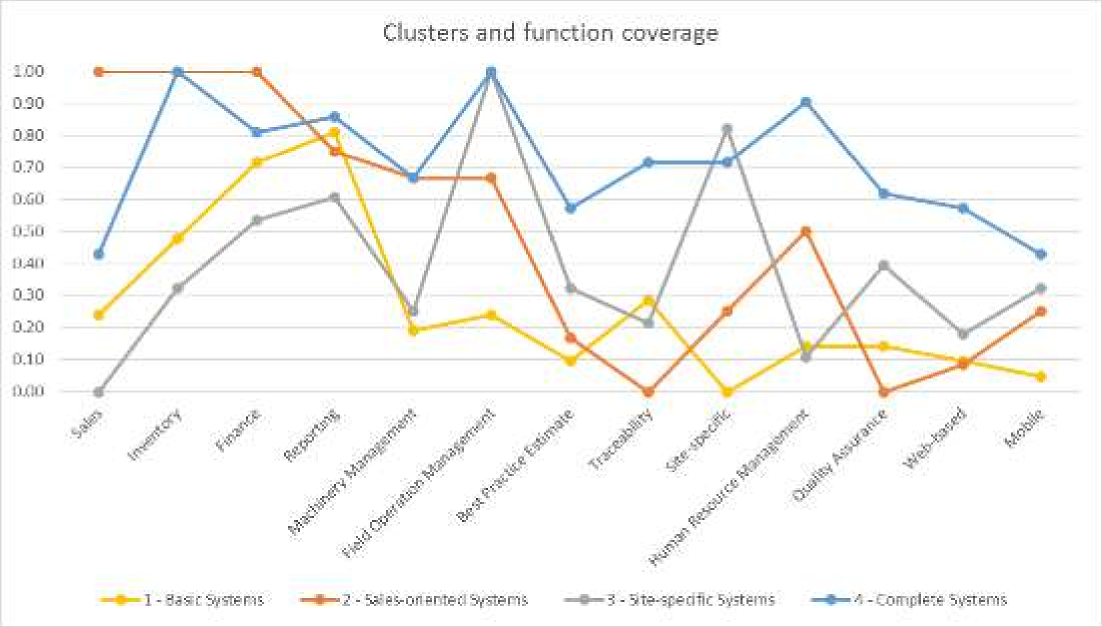


Figure 4: Cluster analysis

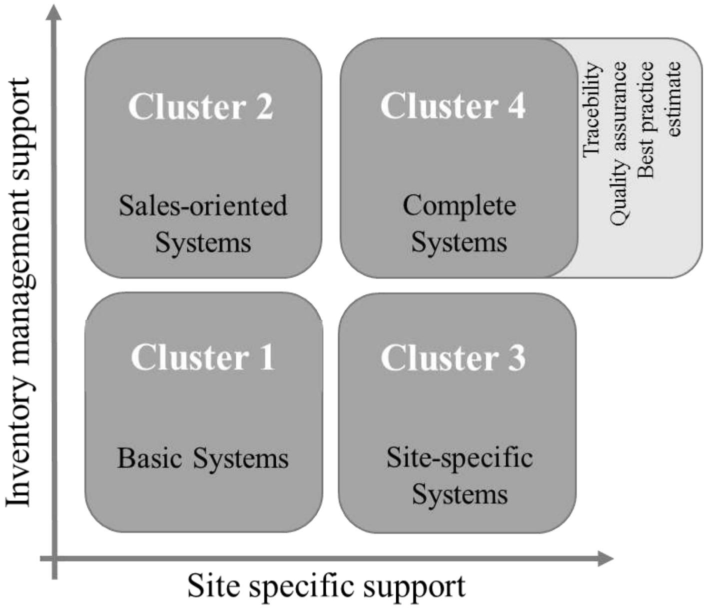


Figure 5: Cluster categories

Cluster 1 is named “Basic Systems” and groups 15 FMIS devoted to cover a limited set of functions, including especially Finance and Reporting. These functions constitute the core of the FMIS systems, and are mainly oriented at supporting a traditional management of the farm, without a specific focus on its particular activities.

Cluster 2 collects the “Sales-oriented Systems” with 13 FMISs that include all the Sales, the Inventory Management, and the Finance functions. These systems cover the product management area of the company, but, surprisingly, also the Human Resource Management function is present in the majority of them. This extension could be connected to the necessity to provide a full costing of products, which requires to include the cost of human labour.

Cluster 3 refers to 21 “Site-specific Systems” which are a homogeneous group of systems that are designed for site-specific purposes in combination with field operation management functions. Half of them offer also a reporting function. More than the 30% is mobile oriented. These features are coherent with the site-specific function, which requires a direct in-field data collection and operation management.

Cluster 4 with 24 FMIS groups the “Complete Systems”. This group owns the widest range of functions. Some of them are fully covered also by the other three clusters, such as Reporting and Field Operation Management. Other functions are offered by only one or two of the other three clusters: for instance, the Inventory function is covered also by cluster 2. Moreover, this cluster offers two functions that are weakly supported by the other clusters: they are the Quality Assurance and the Best Practice estimate functions. Both of them are complex functions that require the coexistence of a large group of other functions: for example, to define best practices, historic data related to inventory, field operations and machines is needed to compare yearly yields and define possible choices. The large majority of FMISs in this cluster includes the site-specific module, showing that this type of functionalities enriches the bundle of already present services. Surprisingly, only the 20% of the systems in this cluster presents a sales module probably because this function is conveyed by external systems not integrated in the FMISs. Nevertheless, this gap could be addressed by future developments, as long as Customer Relationship Management Systems are becoming pervasive. Customer Relationship Management Systems “collect and analyse data on customer patterns, interpret customer behaviour, develop predictive models, respond with timely and effective customized communications, and deliver product and service value to individual customers” [99]. This becomes a remarkable avenue for future investment in combination with the best practice estimation module, creating decision support systems which make larger use of data from the market.

The matrix reported in **Figure 5** presents the four clusters positioned along two dimensions: the support of site-specific activities, and the inventory function. These two functions were chosen because they pave the way to the development of more complex systems. Inventory management is necessary to support the introduction of traceability and quality assurance functions, while site specific features enable the use of decision support systems with best practice estimation, which are the unique functions of Cluster 4.

As an overview of the commercial FMIS analysis, a limited presence of functions for traceability, quality assurance, and best practice was observed. This could be explained by the greater degree of complexity in data processing and interpretation of the results in an automated manner. Therefore, these systems need to be considered as an essential area for future development in FMIS. Moreover, future developments should also address the low penetration of FMIS covering sales by holistic systems as in cluster 4, especially since customer relationship management systems are becoming pervasive.

In conclusion, new complete commercial FMIS based on the integration of inventory management and PA (site-specific) functionalities should include traceability, quality assurance, and best practice estimate functions in the immediate future. The integration of customer relationship management systems in the subsequent years will enable the support of sophisticated decision support functionalities.

2.1.4 Future Perspectives

The analysis of commercial software solutions revealed that current solutions mostly targeted everyday farm office tasks related to financial management and reporting (cluster 1) and, most specifically, those related to sales, inventory, and field operations management (cluster 2). Functions related to traceability, quality assurance, and best practice estimates are still in their infancy in most commercial applications. The support of PA technologies is limited to a small group of systems (cluster 3) devoted primarily to field operations management. Furthermore, the group of systems that cover wider sets of functionalities (cluster 4) lacks basic sales functions. However, it is noted that the future drivers probably will focus on potential internet connectivity, internet of things and cloud computing. It is also noted that future developments of FMIS must to a higher degree involve a closer cooperation between academia and software developers. Studies have the effectiveness of such cooperations through a user-centric and near-practise development process[100]

In general terms, it can also be concluded that despite the best efforts of developers, FMIS still remain on the periphery of agricultural technology and have not yet served their intended purpose as mainstream knowledge transfer tools, or as innovative aids to more effective decision-making[101].

A crucial aspect of FMIS is therefore the knowledge management of the decision processes in the form of dedicated decision support systems. The development of knowledge-based systems based on FMIS in the farming sector require elements like future internet of things, advanced data acquisition systems, machine to machine communication, a Service Oriented Architecture, effective management of geospatial and temporal data, complete ICT supported traceability systems along the supply chain, ICT supported stakeholder collaboration, etc. The process of building knowledge-based systems for agriculture will be supported and supplemented from developments within the industrial setting[102]. Finally, special attention should also be given to interoperability and the availability of standardized formats used on defined data infrastructure elements in the agrifood sector.

Undoubtedly, those farmers and advisors actually using farm management information systems are benefitting. These systems have had a major impact on crop management and provided objective standards. However, functional improvements are still needed to facilitate a wider acceptance within the farming industry.

From this study it can be suggested that future improvements within FMIS should focus on:

- Adopt a user-centric approach to the development and design of FMIS in agriculture
- Serve specific strategies and simultaneously maintain their ability to integrate them in a holistic managerial scheme
- Improve transparency to the operator/manager by providing a user friendly interface. Self-learning and cognition of the operator/manager should not be obscured by the system.
- Establish a dynamic feedback from the soil–crop system to the FMIS similar to the way a farmer would manage each field.
- Establish industry-wide data exchange protocols
- Maintain data integrity and consistency and enhance data capture and manipulation
- Incorporate crop, land and climate databases from a wider area but allow locally-based planning and management at the farm scale, possibly integrating these sources for a better calibration

- Provide the operator/manager with information about resources across the farm and potential impacts of management decisions on those resources
- Require minimal operational training and enhance the relationship between FMIS developers and the end users (farm manager and employees)

2.2 Basic outline and structure for a Farm Machinery Management Information System

Farm machinery is an important part of managing today's farms. Farm machinery cost is the second after land cost. Therefore managing properly farm machinery affects the cost as well as the proper management of the crops. So, a critical part of a FMIS is the management of farm machinery. One objective of the present study was to create a farm machinery management system that could be an integrated part of the FMIS.

The overall objective was to create a basic outline and structure for a Farm Machinery Management Information System (FMMIS) using the soft system methodology (SSM). This approach helped to establish the interrelationships between farm machinery and their surroundings, which will eventually guide into analysing the information flows, defining the databases, knowledge encoding and requirements for advanced FMMIS. Specifically, it is the objective to understand the soft-system activities of the tractor drivers and produce a model of the individual FMMIS components, indicating where the FMMIS will be required to assist/enable information flows. Subsequently, this model will be transformed into a format to conceptualize the future FMMIS using the new technologies that will be developed in farm mechanization.

Generally, the Soft System Methodology (SSM) is based on a participatory problem definition and structuring into a group of stakeholders dealing with complex situations. Such approaches come under the heading of Problem Structuring Methods (PSM)[103]. As a specific part of PSM, Soft Systems Methodology (SSM) is used to analyze human activities, preferable management activities, and to identify user requirements and activity as the basis for subsequent system design[104]. The application of SSM has also been used to describe complex agricultural systems, such as the conceptual framework of a general farm management information system[105] as well as the use of precision agriculture in a university farm[106]. The soft systems methodology was employed where a rich picture of the whole system was developed and from that a conceptual model that infers to daily operations with the tractor, implement and their surroundings.

Initially, a ‘rich picture’ was constructed, which depicts a particular situation or issue of the system under study. Rich pictures show relationships, connections, influences and cause and effects. They are often used to depict complicated situations and should be regarded as the primary structure of a process. In order to be able to model the purposed changes to the analysed situation, the proposed system needs to be clearly outlined and defined. This definition is called the “root definition” and this concept plays a central role in the analysis and modeling as it defines the goal of the system and brings forth various perspectives on a system and the inherent assumptions. The root definition is devised in the form PQR. A system to do P, by means of Q to achieve R or “What to do (P), How to do it (Q), and Why do it (R)”. Special attention should be paid to the elements of CATWOE, a mnemonic word representing the terms Customers (C), Actors (A), Transformation process (T), World-view (W), Ownership (O) and Environmental constraints (E). The core of CATWOE is the T and the W, where the World-view depicts the world view for which the system has meaning and the Transformation depicts functionality on system level. Customers are the ones influenced by the transformation as they benefit and suffer from it. Actors are the ones that carry out the system activity and the Ownership belongs to the ones with the power to initiate or terminate the activity system. Environmental constraints represent elements which are taken as outside the system and imposed on the system.

The empirical data was collected as a result of 30 interviews (formally interventions) targeting tractor operators and farm managers answering questions on the optimal use of farm machinery data as indicators for tractor and implement performance. Specific questions involved specifications on current machinery, current information acquisition on machines, external actors interacting with the machines, experienced problems and issues with the information management on the machines, and potential improvements. The analysis progressed beyond current technologies in FMMIS to also include the future use of autonomous vehicles both embodied as current large sized machines as well as potential small sized vehicles. The interviews were carried out in Denmark and Greece. Respondents were selected from typical agricultural regions in Denmark and Greece representing agricultural practices with state-of-the-art machinery. Denmark is at the front in terms of technological innovations in agriculture[107], while Greece is lagging behind and therefore a more holistic view has been captured (Lawson et al., 2011)[108]. In addition, the major of the Greek farms were cultivating up to 50 ha, while the majority of the Danish farms were cultivating between 50 and 500 ha. In respects to labor use both countries used two field staff per farm holding. Similarities and differences were reported in terms of time spend in the office and outside the office for administrative issues. In Denmark farmers recorded to spend 7 h per week in administrative issues in the office in comparison to only 1 h per week in Greece. Danish farmers spend the majority of the time for accounting and tax papers, while the Greek farmers for applications and regulations. On the other hand, both Danish and Greek farmers spend the same time for outside-office paper work of about 1 h per week, mainly for activities related to consultants and banks.

In Denmark, 13 interviews were conducted in a dense arable farming region in central Jutland involving traditional cash crops like wheat, barley and rape seed. In Greece, 17 interviews were carried out in Thessaly in central Greece, which is the major agricultural region in Greece with the larger fields and larger farm machinery complements and with farm managers/machinery operators cultivating arable crops (cotton, durum wheat and corn). As a follow up to evaluate the proposed conceptual developed models, 15 interviews with a subset of the initial reviewing panel was carried out.

The use of a questionnaire during the research helped to extract valuable information. The questionnaire covered the topics about the tractor technology the tractor information available to the farmers, the external factors which influence the tractor maintenance and finally the tractor developments the farmers needs to do the agricultural work efficiently. From the received answers, the obtained answers were influenced by the age of the farmers and the technology of their tractors. Specifically the young farmers were willing to use new technology on their tractors while the older were not. Moreover all of the asked farmers were interested in learning the recent technological achievements on the tractor systems but the farmers with the old tractors were negative to use them. This occurred because the farmers do the maintenance work of the tractors on their own and they do not trust the new technology and the maintenance work of the authorized workshops. Despite the fact that all farmers, regardless the age of the tractor, were satisfied by the information which they receive from the tractors, everyone was interested in learning more about the new trends of available tractor information. However it is vital to mention that only the farmers with new hi-tech tractors suggested smart ideas for developing the systems of the tractors to make the agricultural processes easier and precise. More specifically, farmers’ suggestions for farm management development were:

- Need for detailed information about farm machinery cost (fuel consumption, maintenance, spare parts)
- Use of GPS for providing optimal route planning and work efficiency documentation
- Automated field mapping using on the go sensors installed on tractors and implements
- Software applications (for smart phones or web-based) for daily record keeping and automatic calculation of machinery use cost
- Wireless control of tractor functions and implements

- Seamless communication between tractors and implements for better management and supervision of tasks
- Seamless updating of data from tractor to PC or server
- Need for a DSS to improve farm machinery management (efficiency, cost, route planning)
- Targeted decision support to improve farm machinery management (efficiency, cost, route planning)
- Applications for incorporating farm machinery data for compliance to production standards
- Automatic integration of field representation attributes (e.g. field boundaries, width of headlands, obstacles) into guidance systems to facilitate implement control mainly for positioning the execution of the operation relative to the headlands
- Applications for synchronous control/positioning of harvesting machines (for grass and grain) and adjoining transport
- Better system for incorporating farm machinery data for the subsidies audit system for N fertilizers, etc.

The use of autonomous vehicles and the relationship with the data generated by the autonomous tractor-implement system was not included in the interviews with farmers, as soft systems methodology depicts only the current situation.

2.2.1 The current situation

By using the voiced concerns and perceptions of the farmers to frame the system under study, the rich picture for the current situation of a Farm Machinery Management Information System (FMMIS) is illustrated in **Figure 6**.

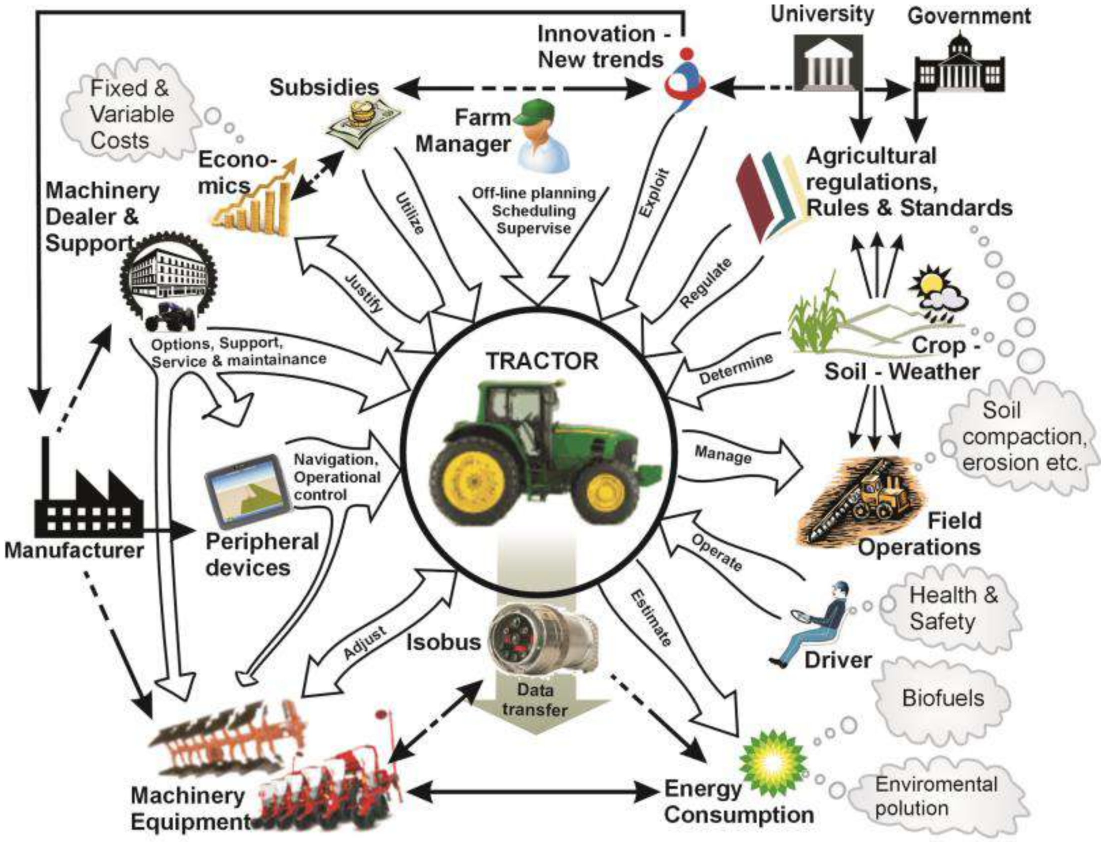


Figure 6: Rich picture for the current FMMIS

As it can be seen, the system structure is very complex and many external as well as internal entities and partners have an interest in the farm machinery complex. It is obvious to note that the tractor is in the heart of the system, while in the study by Sorensen et al (2010) the farm manager was the core part. An important role is also given to the ISOBUS, which is used for the data communication between the tractor and the implements.

Particularly, the rich picture supports further deliberations of the system, which proves itself complex with numerous interconnected external as well as internal entities and stakeholders partners. The machine entity (exemplified by the tractor) is at the center of the system. As part of the complete system, additional devices and sensors are connected (Global Positioning System (GPS), crop sensors (i.e. NDVI), soil sensors (i.e. electrical conductivity)) to obtain adequate data on field status and overall system functionality and performance together with the information derived from the tractor ISOBUS. The acquired data by the FMMIS will be analyzed and processed by specific FMMIS modules and other components and formulated as control actions or decision support guidelines. Additionally, many of the processed outputs are displayed in real time and visualized. The farm manager and tractor operator will be able to monitor in real-time the operation of the tractor-implement system, to calculate various inputs like energy consumption and to monitor, for example, the condition of the fields. Also, the proposed FMMIS enables the calculation of the costs of agricultural tasks in the field, the optimal planning and scheduling of agricultural tasks, the inventory management, and analysis of environmental impacts of various tasks in terms of, for example, energy input. Data from the FMMIS can be transferred to external actors like universities, government agencies, manufacturers and distributors of agricultural equipment to facilitate compliance with standards, provision of subsidies for fuel, seeds, etc. Additionally, it will be possible to convey data and information about farms, specific fields and crop management to universities or research institutes for specialized advice. Generally, the proposed FMMIS will enable the implementation of on-farm experimentation as an important tool for extensive testing and learning purposes.

As mentioned, the tractor acts as the principal decision maker (in terms of automated decision making or decision support for the operator) but at the same time it is extensively connected to the overall farm management. The autonomy includes for example automatic data streaming download of field information (field coordinates, operations history, etc.) when the machine approach and identify the field as well as automatic projection download of for example spatial application rates when traversing the field. The connection to the overall farm management system involves the exchange of information, such as like farmer preferences, and general machine settings. The next step was to define the proposed system that has to be designed and implemented, in terms of the general aim of the FMMIS in the form of a ‘‘root definition’’ as it is addressed in the SSM methodology. The root definition was defined as ‘‘a system to record, utilize and manage the digital data from tractor/implements provided through the ISOBUS, as well as external data related to farm machinery for the purpose of better management of farm machinery performance’’. Based on the defined root definition, the conceptual model for a relevant system promoting innovative change of a FMMIS is illustrated in **Figure 7**.

The key parts of the conceptual model are formulated as activity verbs and in this way building a structured plan for action in order to implement a FMMIS. The boundary of the system makes up the interface between the external stakeholders (i.e. universities, government agencies, retailers), but the stakeholders do not participate in the operation of the FMMIS, which will provide or receive data to and from the system. Inside the system, acquisition, recording, processing and evaluation of data from the tractor-implement system and from the external sensors and instruments will be carried out. The tractor operator and the farm manager reside within the system’s boundary acting as final evaluators of data and decision makers concerning the planning and control of the agricultural equipment.

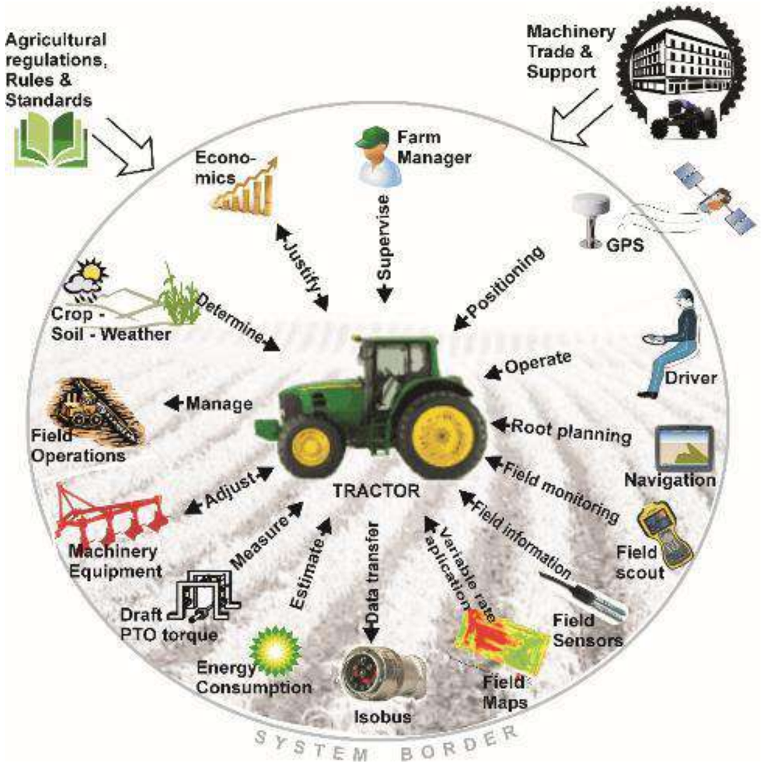


Figure 7: Conceptual model for the current FMMIS

Based on the proposed conceptual model of the current FMMIS and the proposed root definition mentioned earlier, the derived situational elements of CATWOE are listed below:

- <u>Customer</u>: The primary customer of the proposed management information system is the tractor interfacing through the ISOBUS with the implements.
- <u>Actors</u>: The actor is the one operating the management information system, which in this case is the farm manager, farm staff and tractor driver.
- <u>Transformation process</u>: The transformation process involves the transformation of operational tractor/implements data through the ISOBUS to tractor/implements performance status and further guidance instructions for planning and control measures.
- <u>World-view</u>: The world-view is the hypothesis that drives the management information system development. In this case, the view is that operational tractor/implement data are easily acquired and can be used to improve management decision making throughout the production life-cycle.
- <u>Ownership</u>: The farmer is the owner in the way that he has everyday decision making responsibility and decides for the appropriate functions to enable in the system.
- <u>Environmental constraints</u>: The constraints influencing the usability and performance of the management information system and includes the micro and macro situations in

farm production system including production costs, regulations for farm machinery use, safety regulations, as well as environmental provisions.

Before implementation it is necessary to evaluate the proposed system in order to ensure the functionality and maintenance under uncertain, complex and dynamic circumstances (Checkland and Scholes, 1990)[109]. A logical analysis of the model in **Figure 7** must be performed targeting the feasibility of the proposed activity actions using the indices like efficacy, efficiency, and effectiveness. The definitions of these indices for the proposed system stand as:

- Efficacy: Data are easily transferred and used in the tractor/implement system.
- Efficiency: Obtaining all data (input) and transforming it are carried at minimal costs.
- Effectiveness: Machinery performance and the management of decision making are improved.

2.2.2 Future scenarios with autonomous vehicles

Having described the proposed FMMIS depicting current manned agricultural machinery, a future scenario would entail the introduction of a small robotic vehicle, which is depicted in **Figure 8**, and an autonomous tractor, which is depicted in **Figure 9**.

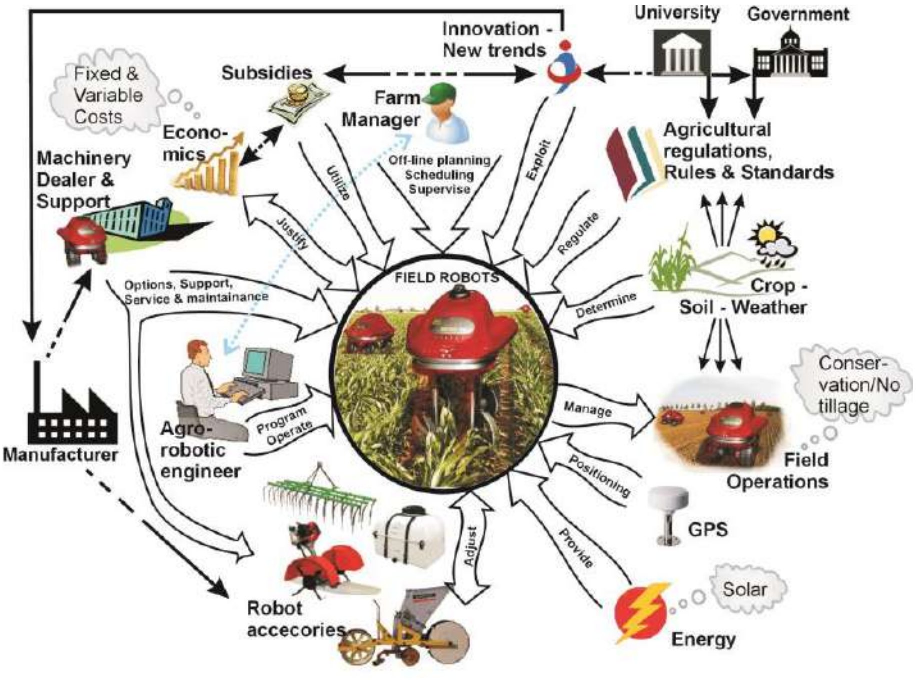


Figure 8: Rich Picture for the robotic FMMIS

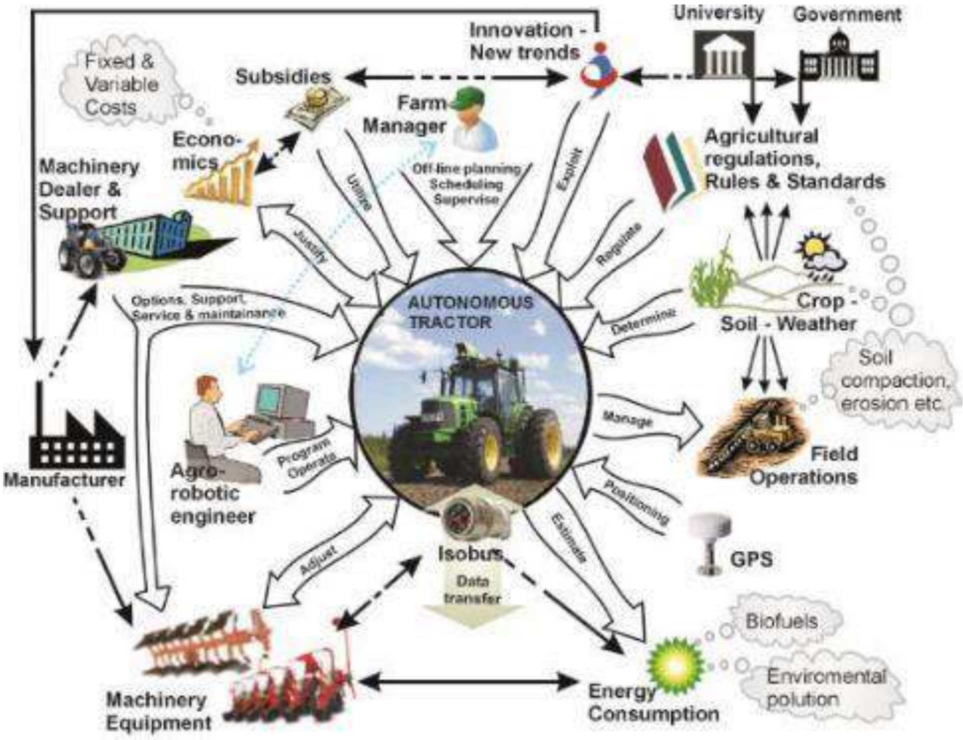


Figure 9: Rich Picture for the autonomous tractor FMMIS

As it can be seen, the two systems are quite similar in terms of structural components and functionalities. Differences include the size of the implements, specifically in the case of the small sized and light weighted field robot. Additionally, in the future robotic era, the tractor operator will be replaced with an agrorobotic engineer who will be responsible for the programming and operating of the two systems. The communication involved with the robots and autonomous tractors and other automation approaches will be also based on the ISOBUS protocol. For this reason, the FMMIS for agricultural robots has the same structure and functions as is seen for the FMMIS for current agricultural tractors. The differences are the inclusion of additional modules for the remote control of autonomous vehicles, for automated management, for operation and control of fleets of autonomous vehicles, and specific additional alerts mechanisms. The terminal in the cab of the tractor is eliminated, as the operation of the vehicles will be fully automated, with vehicles to decide their own operating parameters in the various agricultural tasks, according to the needs arising for the proper and timely execution of these tasks. The proposed FMMIS can support add-ons needed for new devices, new protocols and new software options and tools. Following the conceptual model applied to the current situation (**Figure 7**), the corresponding conceptual model for the structure and functionalities of the robotic system and the autonomous tractor are presented in **Figure 10** and **Figure 11** respectively.

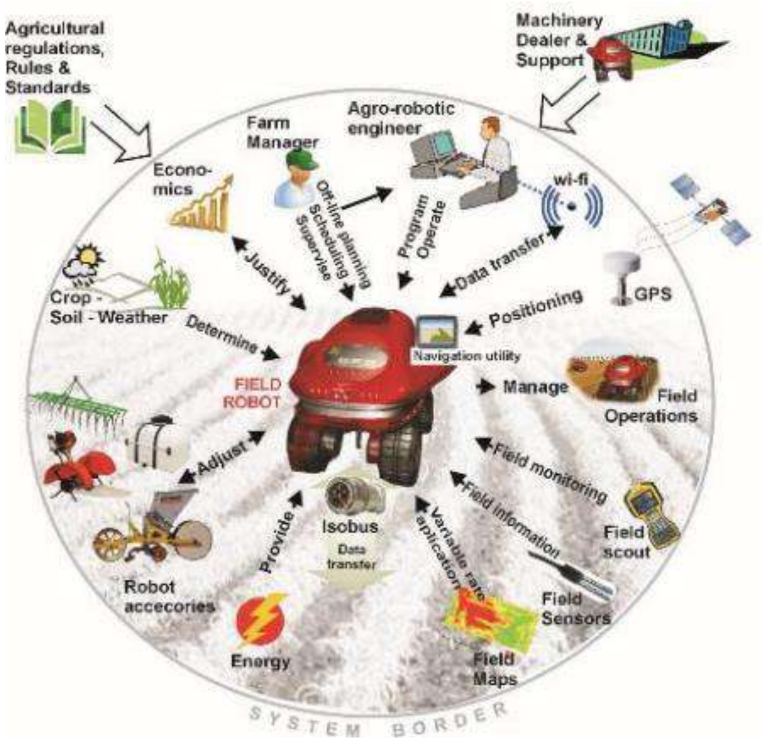


Figure 10: Conceptual model for the robotic FMMIS

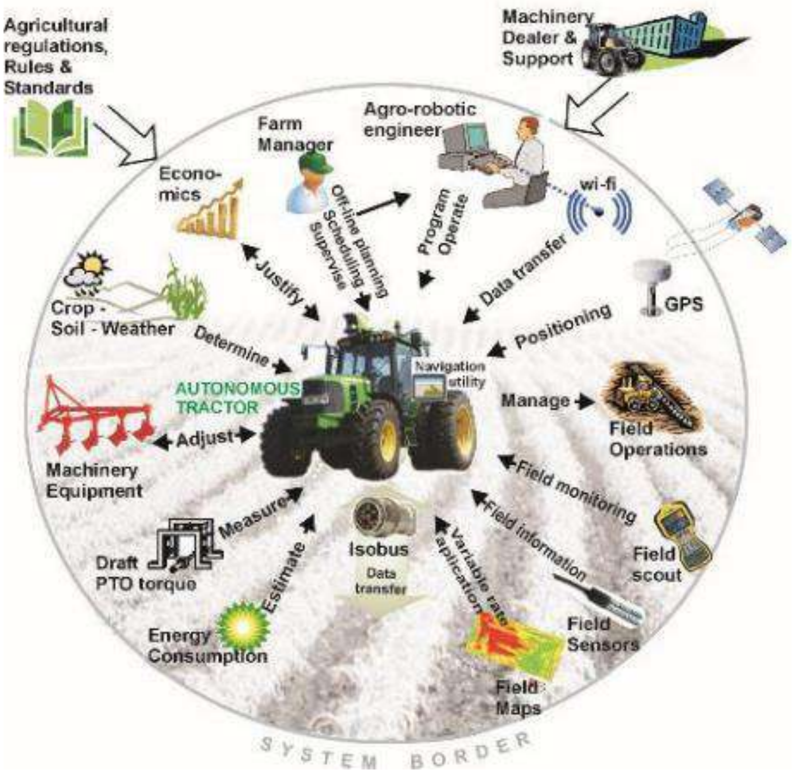


Figure 11: Conceptual model for the autonomous tractor FMMIS

Similarly, the boundary of the system makes up the interface between the external stakeholders (universities, government agencies, retailers, etc.), that will provide or receive data to and from the system. Inside the system, acquisition, recording, processing and evaluation of data from the robot-implement system and from the external sensors and instruments will be carried out. The agricultural robot and the farm manager reside within the system's boundary acting as final evaluators of data and decision makers concerning the planning and control of the agricultural equipment. The definition of the CATWOE in terms of customers, actors, transformations, world-views ownership, and environmental constraints follow the same structure as for the proposed FMMIS for traditional field machinery. The only difference is the elimination of one of the actors, namely the tractor operator. The logical analysis of the two future scenario models is analogue to the logical analysis for the case of traditional technology.

2.2.3 Farm managers' responses to the proposed farm FMMIS

As part of the validation of the proposed FMMIS, five Danish and ten Greek farm managers were asked to comment on the rich pictures and the conceptual models. Personal interviews were carried out at the farmers' premises. The rich pictures and the conceptual models were printed out and presented to the interviewees and their responses were recorded. The general perception was that the FMMIS components are complete and integrate all the actors and the information flows. Also, the impression was that the FMMIS system definition is useful as a facilitator for capturing the needs for better utilization of the data derived from the farm machinery. The individual comments were dependent on the individual experience with ICT tools in agriculture as well as the automated functionalities experienced in current farm machinery. Danish farm managers pointed to the user friendliness as an important aspect in the system, while the Greek counterparts mostly mentioned the financial benefits using such a complete system. Yield mapping, especially for farmers cultivating cereals, was seen as important to include, as well as operations planning especially for crops activities such as irrigation and weed control. On the other hand, farmers managing orchards for fresh produce requested information about the personnel for the manual operations as a supplement to information about machinery that otherwise handles the products. Regarding user friendliness, the farm managers reported that the system must be easily manageable and transferrable between different agricultural machinery (tractors and implements) as well as provide an effective data communication between the field machinery and the farm office. The majority of the farm managers had currently GPS guidance systems installed on the farm machinery and all pointed to their benefits, while farm managers currently not using GPS expressed willingness to invest in such equipment. Finally, some of the farm managers indicated that the system must be easily customized to meet specific needs, including only need-to-have options and control buttons. The youngest farmers stressed the wish to see the farm machinery data, reports and system alerts made available via web and mobile devices.

2.3 Investigation of the factors affecting FMIS and PA tools adoption

The adoption process of technological innovations in agriculture is highly complex because it is affected by a broad range of factors and drivers that could affect the decision to adopt or reject the innovation. Behavioral attitudes, education and awareness, cultural background and norms, social influences, economic and financial variables, policy and market conditions can act as explanatory variables for the adoption patterns of innovation, together with structural and infrastructure factors, availability of support, the characteristics of the innovation itself[110] [111]. Examples from literature have proved that the interaction between potential adopters and technologies to be evaluated for adoption must be considered strongly context-specific.

Literature provides examples of models to analyze the set of factors affecting the decision to adopt or reject technological innovations. The Technology Acceptance Model (TAM)[112] is widely used in the analysis of the determinants of technology adoption. Focusing on attitude and perception aspects, the model identifies two main constructs (Perceived Usefulness and Perceived Ease of Use) as predictors of the final intention to adopt a technological innovation (User Acceptance). The TAM has been developed further and integrated with constructs from other theoretical models[113] [114]. Subsequent adaptations of TAM aimed at identifying the most relevant factors to detect the intention to adopt ICT innovations, both in IT and in the agricultural field[115] [116] and tried to validate additional constructs and items to be considered as drivers of the decision process of new technology adoption. It must be noted, that the strength of factors and drivers affecting farmers' behaviour and their decision to adopt or reject technological innovations depend strongly on many aspects: socio-demographic features of farmers, cultural and social background, characteristics of farms, farming types, type and features of the technology evaluated (e.g. compatibility, costs, profitability, resources savings); external environment (e.g. infrastructure, support from third parties, availability of advisory services, experiences from early adopters, governmental approach, market, financial situation)[117] [118] [119]. The relationship between farmers and technologies (e.g. time spent in getting used to the technologies, farmers' dependence on specific solutions and farmers' involvement in the development of new applications) could play a relevant role also in the adoption or rejection choice of technological innovations[120] [121]. Finally, requests from stakeholders and actors in the agricultural supply chain (such as traceability or demonstration of environmental sustainability) can exert an influence on farmers' behaviour and decisions[122].

The use of FMIS in agriculture has been investigated in depth during the last few years because the adoption of management systems to collect and analyse data from in-field activities has become strategically mandatory to support decision-making processes and gain efficiency. The advent of precision agriculture and related technologies provided farmers with large amounts of available data to be processed[123]; therefore, information flows and their management, and the consequent support to decision-making are the very critical issues that FMIS must cope with. During recent years, the development of FMIS has led to the incorporation of more sophisticated functionalities, with the aim of increasing FMIS compatibility with existing technologies, their capability of collecting and processing data, their effectiveness in supporting decision-making. Nevertheless, contributions in the literature have highlighted that their adoption is affected or can be conditioned by some critical factors. Nikkilä et al. (2010)[124] pointed out that usability, reliability, availability, resources saving, convenience, ease of use and connectivity are critical features for end-users when evaluating FMIS. On the other hand, unintuitive or excessively complicated systems, or extremely wide sets of features provided by FMIS could cause misuse and be responsible for low levels of adoption[125]. Murakami et al.[126] provided a list of requirements that information systems should possess to support precision agriculture technologies such as integration with existing systems, interoperability with other software packages and data sources, scalability and accessibility. Sørensen et al.[127], the interoperability and the transfer of information between systems are mentioned as significant issues to be improved in future FMIS, with the aim of meeting farmers' needs in terms of FMIS functionalities and interfaces. The difficulty in assessing the intangible benefits of information system improvements, and the influence of farmers' computer readiness on the perception about the value of information systems must be included among the critical factors affecting the adoption of FMIS[128]. In addition, other factors such as socio-demographic features of farmers, software fitting and matching with existing systems, ease of use, time and money saving can influence potential users' decisions to adopt FMIS[129]. Similarly, compatibility between hardware and software, adaptability, flexibility, reduction of training needs, and provision of useful and ready-to-use information outputs must be included among the features that FMIS should have to enhance their diffusion. Although returns from FMIS adoption in terms of better data management and support to decision making could not be easily quantified by end-users, benefits of the introduction of FMIS should be clearly identifiable and measurable in terms of key performance indicators.

Evidence from the literature confirms that advancements and improvements in FMIS design and modelling cannot overlook the interaction with farm stakeholders, the identification of the scope of a system, boundaries, processes and actors asking for specific requirements of the systems. In the light of these premises, it follows that exploration of the most pertinent factors that affect the intention to adopt FMIS must be deepened, together with a careful evaluation of context-specific variables that could affect farmers' behaviour and perceptions.

2.3.1 Methodologies to estimate FMIS adoption

A preliminary qualitative analysis was done to understand the attitude of farmers towards ICT innovations and evaluate the adoption of new software solutions for farm information management, together with the relevant steps of the decision process and the intervening factors.

Qualitative approaches are usually adopted to conduct in-depth investigations on relatively unexplored topics, as they serve as a tool through which relationships between complex concepts and underlying influencing factors can be identified[130]. They base on exploring people's behavior, attitudes, experiences and opinions about specific topics, trying to highlight underlying or latent mechanisms and interactions between factors. Since qualitative methods are largely inductive, they are particularly suitable to approach under-studied phenomena and to develop hypotheses for further research steps[131], helping in providing context and foundation for quantitative analyses.

Qualitative techniques are generally conducted on small numbers of pre-selected targeted participants; therefore, they enable to discern and assess the relevance of interviewees' experience facilitating the understanding of central and fundamental features of a specific phenomenon[132]. Among the available qualitative research methods, in-depth interviews with experts and focus groups with practitioners were selected. In-depth face-to-face interviews were chosen, as they are considered optimal for collecting data on individuals' history, perspective, and experience; moreover, they help in providing a wide overview on the topics under discussion, from the observers' perspective.

Focus group discussion is a qualitative research approach whose main assumption is that many relevant research variables (such as motivations, opinions, behaviours, preferences, etc.) originate through social interactions between individuals into a shared context, recreated by the focus group[133]. The interaction between group members is the distinguishing feature of this technique; focus groups are typically performed during explorative and preliminary research stages, with the aim of letting researchers become familiar with the analysed phenomenon and the context it belongs to, and identify independent, dependent and control variables[134]. Since the aim of the qualitative step of the analysis was to identify the most relevant constructs and drivers in the technology adoption process, focus group method was considered suitable for this investigation. Even though focus groups showed some limitations, they enable large amounts of qualitative evidence to be collected, and favour the emergence of experiences and themes[135]. In particular, they control the interactions and synergy among participants to deepen the investigation of complex behaviour and motivation because the discussion between interviewees provides valuable insight about the extent of consensus and divergence among the group[136].

2.3.2 FMIS adoption in agriculture analysis

On the basis of the literature review outcomes, a semi-structured qualitative schedule was defined; for focus group discussions, the outline was prepared with the aim to provide a structure for the focus group procedure, including a time frame and the identification of key questions (relevant questions, to be mandatorily asked) and secondary questions. In-depth interviews and focus groups discussions dealt with the same topics and were conducted following a similar sequence of questions. The two complete outlines are included at the end of this thesis, as annexes (Annex 1 and Annex 2).

In total, six focus groups were established in three countries (Greece, Italy and Turkey). A maximum of 10 participants per focus group (recruited among farmers and technicians) were invited to discuss selected topics according to a specific semi-structured protocol aimed at stimulating their interaction.

The structure of the protocol consisted of 4 main sections, listed below:

- Organizational and professional tenure: the aim of this section was to collect information about farm business and income (in case respondents are farmers), farm size, number of employees and level of specialization, land and/or equipment ownership, professional tenure and role, education and age. The section was meant to draw a picture of the farm, trying to understand the role that “socio-demographic” features (both of the farm and the farmer) play in affecting the technology adoption decision processes.

- Technology adoption in agriculture: this section was composed of questions whose aim was to understand the role of technological innovations in agriculture and the relationship between farmers and technology. Respondents were asked to express their opinion about technology adoption in agriculture and its role, and to declare their level of knowledge and trust towards technological innovations; furthermore, attitude of farmers towards technology, previous experiences and perspective, and the degree of confidence towards technological innovations were analyzed. Finally, respondents were asked to identify some "socio-demographic" features of the farm that could influence or could have influenced any decision and experience regarding technology adoption. This section aimed at exploring and collecting respondents' attitudes, opinions and experiences about technology adoption, trying to outline the set of constructs and drivers that compose and determine the adoption process.
- ICT/Technological innovations' adoption process: since the adoption of a technological innovation can be seen as the final stage of a decision process, this section firstly asked the respondents to focus on the phases that compose this process. Then, respondents were asked to identify what are the most important factors/drivers that affect each stage of the decision process. Finally, all the inputs from the discussion were collected and schematized into a diagram, where the main steps of the decision process are represented in rectangles, and the related influential factors in the ellipses. The aim of this section was to try to define the main constructs characterizing the technology adoption process, the factors they are influenced by, and the relationships that link constructs and factors.
- Opportunities and limitations: the last section asked the respondents about benefits and limitations resulting from the adoption of technological innovations, and on which farm areas benefits/opportunities and limitations could be more influential, according to respondents' opinions or direct experiences. Furthermore, the section asked the respondents to focus on potentialities that could make technological innovations more likely to be adopted. Finally, the last question invited respondents to express their opinion about what technological innovations are missing to satisfy users' needs. The aim of the section was to collect additional opinions and ideas about drivers to be enhanced, (or factors to be adjusted) to encourage the process of technology adoption.

The main objectives of the focus groups were:

- To identify the main factors affecting the decision to adopt a technological innovation (new FMIS);

- To list the steps leading to the adoption of a technological innovation;
- To identify the links between the steps of the process of adoption and the factors that could influence each single step.

Results are shown in **Table 3**, which provides a summarized overview on the outcomes of the focus group discussions. Interviewees agreed upon a "six-steps" decision process for the adoption of information management technologies in agriculture:

1. Identification of needs
2. Evaluation of available solutions
3. Analysis of scenarios (comparisons of solutions and investments)
4. Risks/Benefits analysis and Return on Investments
5. Adoption
6. Evaluation after use.

Table 3: Summary of the outcomes of the focus group discussion

Factors / **Adoption steps**	**A. Features of farms and farmers**	**B. Features of technological innovations**	**C. Features of external environment**
1. Identification of needs	• Age • Education and culture • Propensity • Open-mindedness • Entrepreneurial orientation • Planning orientation • Company's size • Production type • Income/Economic status	• Complexity of needs (short term vs. long term solutions) and of technologies under evaluation • Type of technology and profitability	• Future growth perspectives • Voluntariness/Legislation • External/Third parties' influence (consultants, technicians, associations)
2. Evaluation of available solutions	• Age • Open-mindedness • Perception of risks	• Ease of use • Usefulness • Reliability	• Third parties' participation to innovations

	• Company’s size	• Usability • Functionality/Identifiable performances • Flexibility • Path dependence from the adopted innovation	• Word of mouth and experience sharing (early adopters) • External/Third parties’ support
3. Analysis of scenarios (comparison of solutions and investments)	• Anxiety/Fear • Awareness raising • Training • Initial investments • Company’s perspectives	• Usefulness • Observability of performances • Effectiveness • Complexity • Degree of fit and compatibility • Trials and tests on the field • Perception of costs/benefits	• External/Third parties’ support
4. Risks/Benefits analysis and Return on Investments	• Age • Education • Anxiety/Fear • Familiarity with innovations • Income/Economic status • Production type • Costs and benefits/ROI	• Usefulness • Effectiveness • Perception of costs/benefits • Profitability • Price/Performance ratio • Path dependence from the adopted innovation	• External/Third parties’ support • Financial support • Policies/Legislation
5. Adoption	--	--	--
6. Evaluation after use	• Training	• Performance • Trials and tests on the field • Compatibility • Usability	• External/Third parties’ support

Three main groups of factors influencing the adoption decision process were identified during the focus groups.

A. Features of farms and farmers

According to the interviewees, structural features of the farms (e.g. size, income), socio-demographic traits of farmers (age, education) and farmers' perceptions and orientations toward innovation and entrepreneurship are particularly relevant in the first steps of the decision process regarding the adoption of technological innovations, since they can affect the identification of the needs and the evaluation of the available solutions. Then, in the subsequent stages of the decision process (before adoption), additional farmers' features (such as awareness, knowledge gaps, anxiety, uncertainties, familiarity with innovations) were mentioned as particularly influential, as they seem to become relevant when risks/benefits analyses are performed. In these advanced stages of the decision process, economical characteristics of the farms and their development perspectives (both in terms of business and Return of Investment (ROI) play an important role, because the introduction of new systems for data collection and information management can require significant organizational changes and investments. Availability and provision of training were also mentioned as important factors affecting the decision about adopting innovations: training is fundamental to fill knowledge and experience gaps. Nonetheless it could absorb considerable financial resources and reduce labor hours. Therefore its role in the decision process becomes fundamental especially in the last steps of the process and after the adoption. In fact, being perceived as an investment, training must be available as soon as the innovation is adopted, to make farmers familiar with the new technologies and avoid misuse, inefficiency and rejection.

B. Features of technological innovations

Focus group discussions highlighted the influence of this group of factors on all the steps of the decision process regarding the adoption of new FMIS. In the first stages of the decision process when available solutions are considered, innovations seem to be evaluated according to their "functional" features (such as usability, ease of use, functions, flexibility, reliability). Usefulness was considered by participants as a fundamental feature for ICT innovations during all the stages of the adoption process; path dependence from innovations was also mentioned as critical both in the initial and in the latter stages of the decision process, since it could be a constraining factor. When economical evaluations and comparisons become a relevant part of the decision process, additional factors such as effectiveness of the innovation, complexity, degree of fit and compatibility with existing systems, observability of performances, perceived costs and benefits, profitability, and price/performance ratio are taken into consideration. Return on Investments is a pivotal variable that many interviewees mentioned. Insofar as technological innovations might be viable and useful, their evaluation and adoption depends also on their profitability, on investments needed, and on farmers' exposure to risks.

Finally, the fundamental role of trials, field tests, and successful adoption experiences was acknowledged by all the interviewees: in-field demonstrations and cases of pilot farms seem to be a powerful driver to promote the adoption of a technological innovation, and to favor its diffusion among end-users.

C. Features of the external environment

A strong influence of the external environment on adopting technological innovations was acknowledged by interviewees, affecting all the steps of the decision process. Market environment, agricultural policies and legislation, and funding policies define the context in which farmers elaborate on their decision, and exert an unquestionable influence on all the stages of the adoption process. Stakeholders of different nature can orient the decision of adoption and could even force the adoption of specific technological innovations through legislative obligations, or could boost it through supporting measures and economic stimuli. Alternatively they could discourage it controlling different facilitating conditions, such as "innovation-friendly" policy orientations, public funding, and financial support against market risks.

The technological framework surrounding an innovation plays a relevant role: the provision of up-to-date and easy-to-use solutions, along with new approaches for their dissemination (e.g. shareware, open source tools) could promote a faster diffusion of new ICTs, thanks to the reduction of required financial effort and to the availability of affordable solutions.

Word of mouth, sharing of experiences, and contacts with early adopters were listed by participants as influential factors when deciding on the adoption of new FMIS, especially in the first stages of the decision process. Information by pilot farmers, successful or negative experiences of early adopters, and the chance to evaluate concrete results and performances of the innovations seem to be a more reliable reference system for farmers to trust, and to consider when evaluating adoption.

Informants mentioned external support, as a pivotal factor affecting the decision to adopt: qualified external support from technicians, consultants and associations is sought both when available solutions are evaluated, and when the final risks/benefits analysis is performed, since experts' knowledge and experience can increase farmers' awareness and trust toward innovations. External third parties' support can bridge farmers' knowledge gap regarding potential usefulness and profitability of innovations, and enhance their confidence thought demonstrations and trials. Moreover, the involvement of external trusted third parties (such as governments, research institutes, associations) in the development of technological innovations seems to act as a guarantee of reliability of the innovation itself, and increases the likelihood of adopting.

As a conclusion, the results of the focus group discussions confirmed the importance of well-known factors as influential drivers in the decision process regarding the adoption of new FMIS. Focusing on a specific innovation (new software), some of the factors mentioned in literature were stressed more than others, and some cues for further discussions were provided. The attempt to define the steps of the decision process regarding the adoption of technological innovation and to identify the most relevant drivers affecting each step can be considered a valid suggestion to set up further studies in this area.

The outcomes of the focus group discussions clearly pinpointed that the dynamics underlying the adoption processes of technological innovations are markedly country-specific, "context"-specific, site-specific, technology-specific and farmer-specific. Given this extreme dependency on the context, further analyses to measure the relative importance of the relevant factors affecting the adoption of technological innovations, and the relations among them (e.g. moderation, mediation) was advocated, building a theory of adoption specific for the agricultural practice.

3 Results

3.1 Development of the FMMIS

A wide range of technologies and tools have become available for capturing, storage, analysis, wireless transmission, visualization, use and sharing of digital data and information in recent years. Several of these technologies are integrated in platforms that facilitate digital data and information use. In addition, farmers collect the data from their daily activities and field operations either through online sensors or manually and in many of the cases at paper format. The necessity to register all activities, as inputs and outputs for farm activities has been enforced by the Cross Compliance requirements by the European Commission. There are a number of software solutions to register these data at farm office, but the ability to gather precise application data at field level is limited, especially when it is referred to use application of fertilizers and pesticides using modern tractor and implements.

At material and methods section, 141 commercial FMIS from Europe, North America, and Australia were reviewed. After defining eleven functionalities that an FMIS can support (see **Table 2**) and verifying their presence in the sample of commercial systems, a cluster analysis was conducted to identify homogenous groups of systems. The cluster analysis revealed four clusters named according to their main features. One of the clusters presented a higher level of complexity supporting functions weakly represented in the systems of the other three clusters. The reason could be that these high level functions–traceability, best-practice estimate, and quality assurance–require the integration of data from different sources (e.g. field and operations, machines, HR). Therefore, they can be deployed only when the overall system reaches a certain level of completeness and complexity.

Two dimensions were identified as the thresholds towards two possible pathways of development of more sophisticated systems. Inventory management makes possible to develop traceability and quality assurance. Site specific functions support the inclusion of decision making functionalities. Future FMMIS should go in the direction of combining site specific and inventory management functions in order to collect enough data to convey a reliable support decision making process and solid traceability and quality assurance functions.

This thesis envision a promising way for the development of a FMMIS in the integration of site specific functions into a sophisticated decision making environment, where farmers and technicians are provided with reports to improve their choices and increase the yields of their crops. This would be possible only if data from sensors are processed to the specificities of the agricultural practice. The integration of precision agriculture solutions and the decision support of a FMMIS can pave the way to a more fine grained process. New research efforts could be dedicated to the definition of a straightforward stepwise process to elaborate the rich and complex data from sensors. Therefore, the decision support of the FMMIS would be able to provide farmers with just the relevant data for each activity and choice to make. A challenge for future FMMIS is in this meso-level of data elaboration: only the systems able to "make sense" of the richness of the data provided by sensors and "advise" the farmer on possible options will differentiate in the competitive arena.

The evolution of ICT technology and the development of the ISOBUS protocol have advanced significantly the development of automation in agriculture. The difficulties in reading and recording the complexity of the agricultural environment have to large extent been overcome and already the first steps to automate agricultural operations have emerged. For developing the "future" FMMIS an action plan able to fully exploit all these new technologies and striving toward full automation of all tasks needed in the management and the operation of a farm was proposed. This system is compatible with the latest generation of tractors and agricultural implements, and with the future autonomous vehicles applicable for agricultural operation and incorporates the new trends of on-the-go and in situ sensors as well as ISOBUS data transfer protocols For this purpose, conceptual models capturing these structures and functionalities were derived (see **Figure 7**, **Figure 10** and **Figure 11**).

Finally, despite the huge changes, that 4th Industrial revolution (Industry 4.0 – IR4), is bringing and the support of governments and organizations for increasing the acceptance, adoption rate of PA technologies (e.g. subsidies to farmers for purchasing new smart technologies for minimizing environmental impact of agriculture), is still lagging behind. A lot of research has been carried out for identifying the reasons for this problem[137] [138] [139] [140], with the main one to be farm size, which is related to farm income and the ability of the farmers to invest in the new technology. Additional reasons consider from the farming community is the reliability and accuracy of existing solutions and sensors and finally their user friendliness and usability (which is related mostly with the aging and the education level of some farmers, as well as with the complexity of some solution).

Consequently, the question that has to be answered is how the new IR4 technologies can help increasing FMMIS adoption into farming community. For answering this, question the main factors that affect farmers' decisions on purchasing such was studied in this thesis. The summary of the factors that are important are shown in **Table 4**.

Table 4: Main factor affecting adoption

Characteristics	Factors affecting their decision/adoption
Structural features of the farm (size, income)	○ Price of PA technology ○ ROI - Return on investment ratio ○ Perception of cost / benefits ○ Profitability
Demographic traits of the farmers (age, education)	○ Easiness of use ○ Familiarity with innovations ○ Complexity ○ Training
Functional features of the PA technologies	○ Reliability ○ Accuracy ○ Usefulness ○ Usability ○ Flexibility ○ Effectiveness ○ Case of use

Therefore, the FMMIS, must be able to meet the aforementioned factors in order to be adopted from the farming community and especially from the small farms, in which the cost of the technologies is effecting their adoption rate.

3.1.1 FMMIS architecture

As the aim of this thesis was the development of a holistic FMMIS as analyzed at Materials and Methods, the developed FMMIS supports data inputs from tractors, agricultural machineries, Unmanned Vehicles (robots), sensors installed at the fields and from various services (e.g. weather services, earth observation services). The simplified diagram with the main entities of the FMMIS is presented in **Figure 12**.

The information process is the follow: field data (sensors, machines, services) is transferred to the central depository (database) of the FMMIS where the data is stored. The data can be view from end users by applying queries through the graphical user interface (GUI), or to be analysed by the Decision Support System (DSS) for assisting end users on making management decisions.

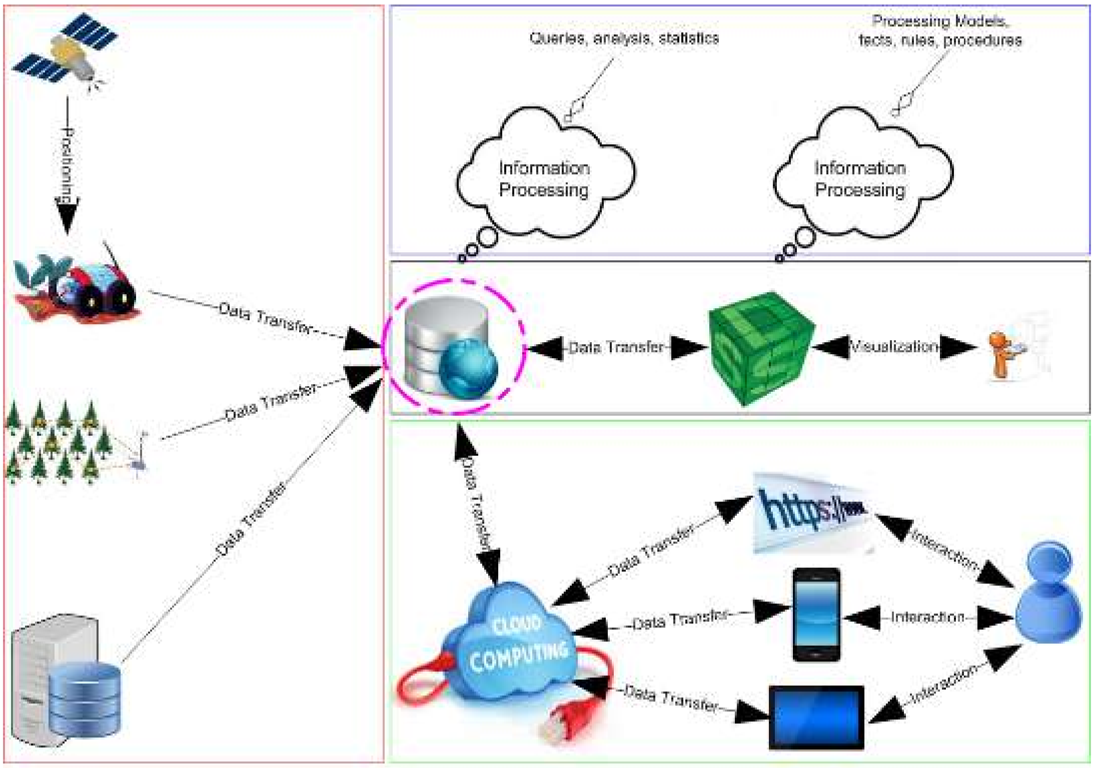


Figure 12: Simplified diagram of the information process of a FMMIS

Respectively, the simplified diagram with the main entities of a holistic FMMIS is presented in **Figure 13**. These are:

- The **users** of the system
- The **farm**
- The **fields** of the farm and its components (crops, plots, etc.)
- The **vehicles and machineries** of the farm (tractors, unmanned vehicles, agricultural implements)
- The **sensors and external services** (in situ sensors, remote sensors, weather services etc.)

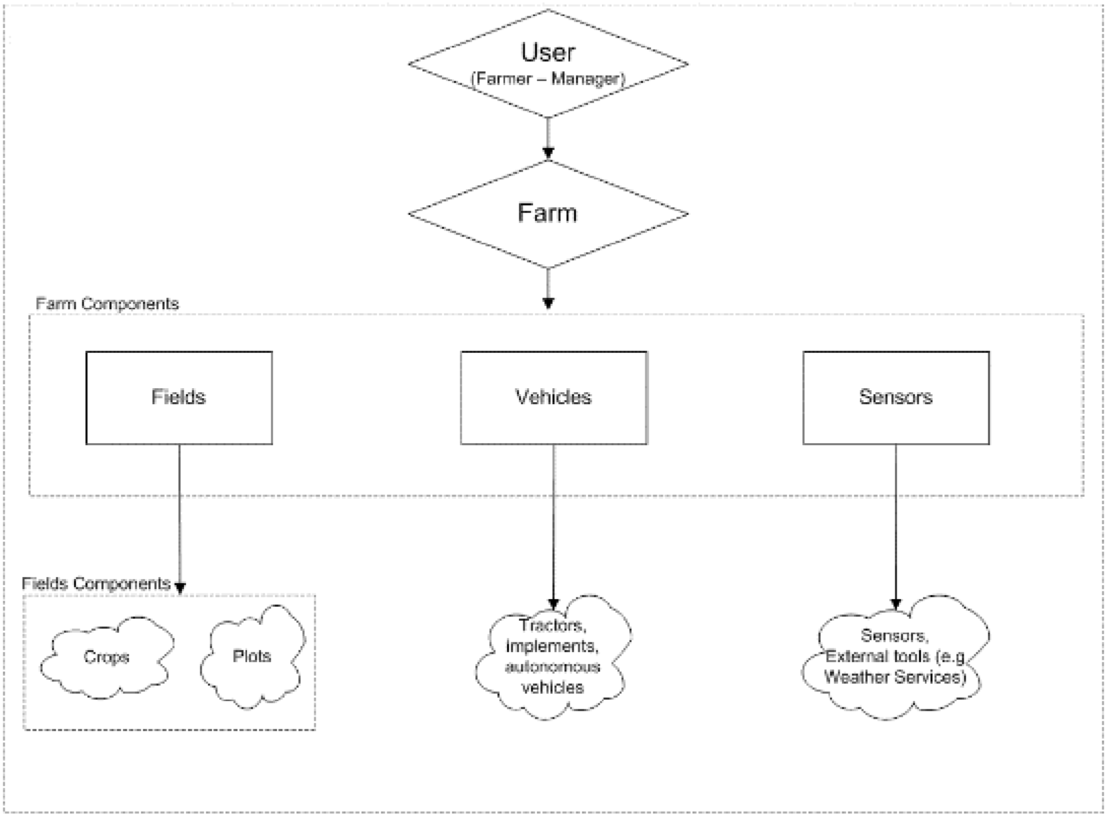


Figure 13: FMMIS main entities

In addition, a holistic FMMIS has to support various functionalities, as these are exported from the review of commercial FMIS applications (**Section 2.1.2**) and the basic outline and structure for a Farm Machinery Management Information System (FMMIS) (**Section 1.5**). These functionalities (modules) are explained in **Table 5**, and projected in **Figure 14**.

Table 5: FMMIS modules

	Module Name	**Module Tasks**
1	Real Time	Real time data transfer from: • Unmanned vehicles • Tractors • Implements • Sensors (e.g. moisture sensors) • External Tools (e.g. Weather services)

2	Cartography	• Route maps • Field maps • Plot maps • POI (Point of interest maps) • Real time maps (Routing) • Spatial maps (interpolated maps) • Prescription maps
3	Logger	Data logging (collection) from: • Unmanned vehicles • Tractors • Agricultural implements • Sensors (e.g. moisture sensors) • External Tools (e.g. Weather services) • Event logs
4	Control and inspection	• Remote manual control of unmanned vehicles, sensors etc • Set working parameters of unmanned vehicles, sensors etc. • Set automation rules of unmanned vehicles, sensors etc. • Inspection of working parameters
5	Finance	• Incomes • Outcomes • Sales • Purchases

6	Analysis	Analysis and view of all data using: • Tabular form (tables) • Charts • Gauges • Maps
7	Management	• User Management • Employee Management • Warehouse Management • Yield Management • Calendar
8	Inventory	• Materials • Vehicles • Sensors • Personnel
9	Treatments	• Tillage Treatment • Irrigation Treatment • Crop Treatment (fertilization, spraying, etc.) • Harvesting • Post Harvesting
10	External Data Tools	• Upload of external databases from other tools (e.g. other FMMIS systems) • Upload of external files (e.g. excel files, GIS files, GPS files etc)

		• Export of system data to various types (e.g. xls, shp, csv, images, JSON, GeoJSON etc.)
11	API	• Bidirectional data transferring between the FMMIS and external tools/databases
12	Alerts	• View system alerts • View vehicle alerts • View sensors alerts • Fault Diagnosis
13	Traceability	• Traceability with use of QR code
14	Reports	• Creation of various types of documents (e.g. documents needed from national ministries) • Data reports
15	Agricultural Standards	• Database of agricultural standards and rules • Quality insurance
16	Best Practice	• Propose Treatments (e.g. irrigation quantity) • Propose working parameters of tractors and implements

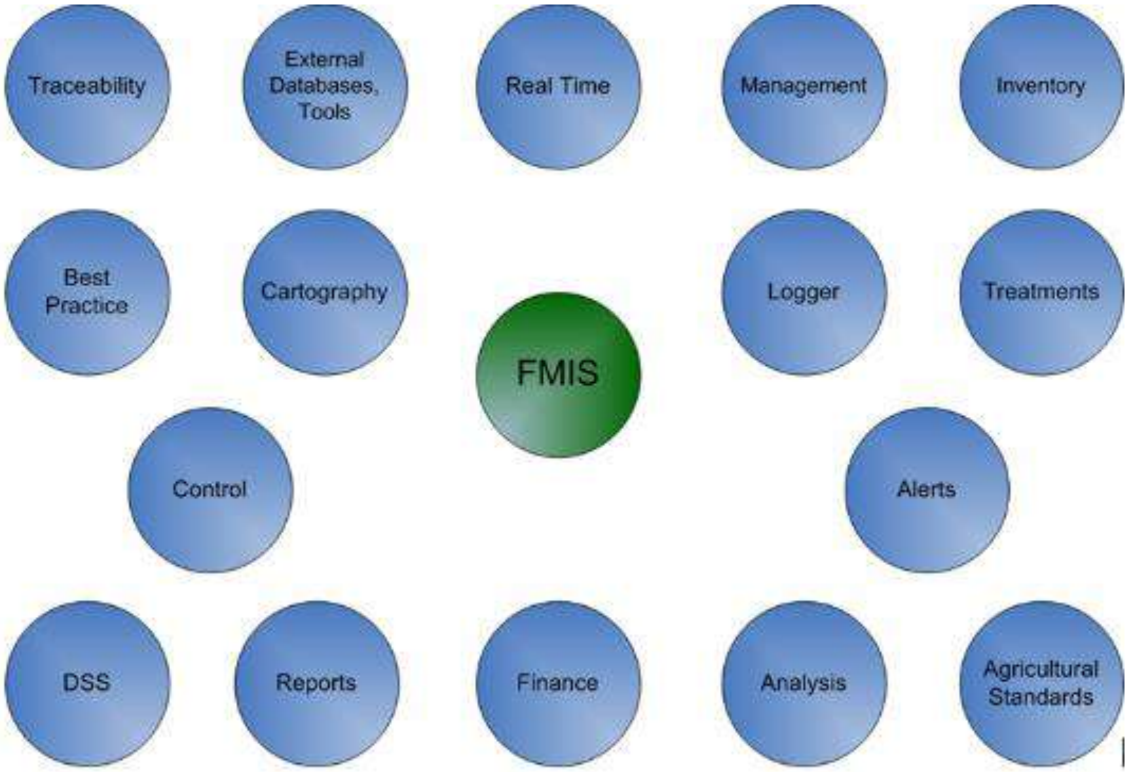


Figure 14: FMMIS modules

As the number of the FMMIS modules is quite big, these were grouped into a small number of different functionalities which used for defining the structure of the database, which is the central point where the data are stored. These functionalities are:

- **Users' management**: It contains the main info for each user in combination with his/hers access rights.
- **Farm management**: It contains the details of the farm, including the crops and the spatial data of the fields (e.g. boundaries).
- **Inventory management**: That includes the registration of the details of the inventory of the farm (tractors, unmanned vehicles, agricultural machineries and sensors).
- **Calendar**: The calendar is combined with the **warehouse, personnel and financial management** information where each input and output (e.g. purchase of fertilizer and its price) or action (e.g. personnel effort) at the farm is being recorded for monitoring and analysing the financial aspects of the farm, but also for keeping a calendar record with any action performed.
- **Yield and Treatments Management**: Each treatment and harvesting data of each crop and field, are recorded for a detailed analysis of the impact of each treatment in the crop performance.

- **Data management (sensors, machineries etc.)**: Data coming for each possible source is recorded and analyzed. The data input supports georeferenced data recording, for enabling spatial capabilities to the FMMIS.

3.1.2 FMMIS database development

The structure of the tables was developed in such a way in order to provide extreme interoperability with systems, tools, and services that were not predicted or existed during its implementation, as a key feature of FMMIS is the ability to be compatible with data coming from sources that were not anticipated in the original design, for allowing the final system to be compatible and to be able to analyze any type of data. To achieve this, the database stores the data of every different entity as sensors, tractors etc. (**Figure 15**) in just one table for each entity and uses the technology of the rotating tables by executing the necessary queries. In this way, the final system is able to separate and to analyze data from sources (e.g. sensors types not existing nowadays) unforeseen in the initial design. The final database table structure is projected in **Figure 15**.

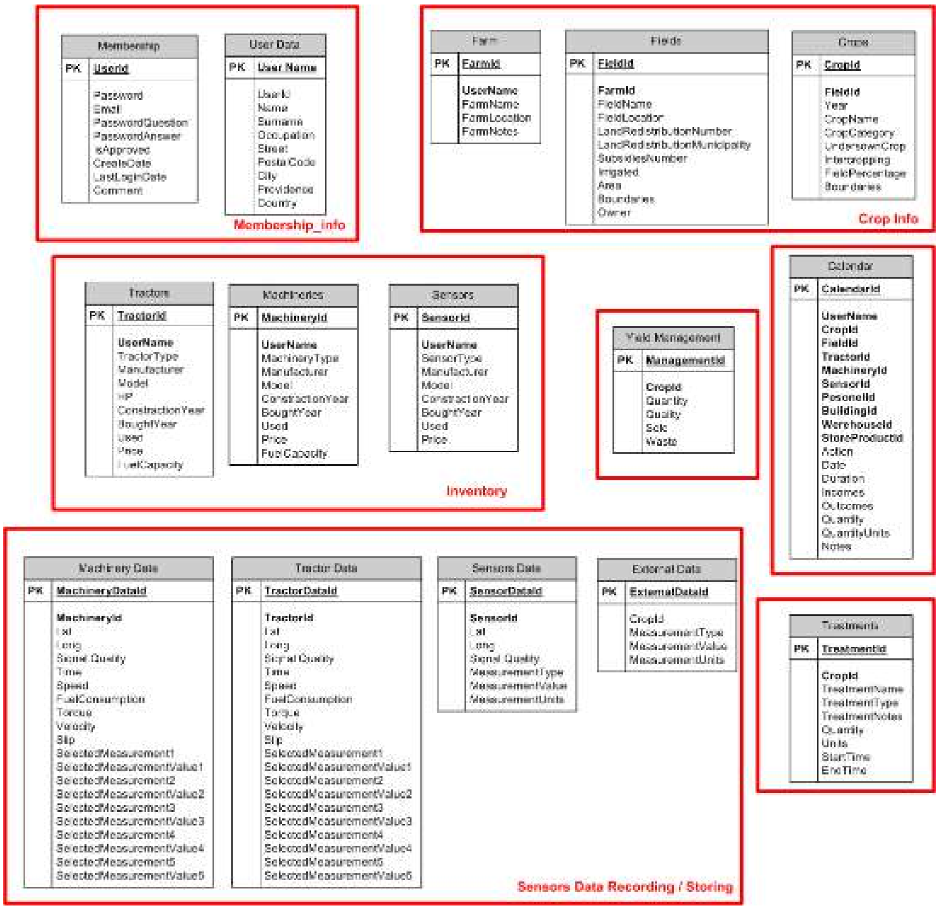


Figure 15: Main database tables

The database development was made using Microsoft SQL Server. The Microsoft SQL Server is a relational database, which was developed by Microsoft. The main languages used are T-SQL and ANSI SQL. The main data storage unit is the database which is a collection of tables and code.

For geospatial data storing and transferring, a binary equivalent, known as well-known binary (WKB), was used. The exact formats were originally defined by the Open Geospatial Consortium (OGC). The current standard definition is in the ISO/IEC 13249-3:2011 standard, "Information technology -- Database languages -- SQL multimedia and application packages -- Part 3: Spatial" (SQL/MM). Through this standard, the database supports storing and projecting of 2D and 3D geometries.

Moreover, various Microsoft SQL Server services used for successful, safe and quick querying, processing and transferring of data. Some of the main services used are:

- “Service Broker” that runs as part of the machine databases and provides a reliable messaging platform and waiting messages to the central SQL Server applications.
- The synchronization service (Replication) used by the Microsoft SQL Server to synchronize the databases, either completely or as a subset of objects. This also helps in cases where the parent database stamping, enabling even for automatic operation of the secondary synchronous database.
- Analysis Services that add capabilities and complex OLAP data recovery for SQL databases.
- The Data Reporting Services gathered from Microsoft SQL Server. In this way it is possible to produce a web report (Web Report) almost automatically without programming HTML, CSS or JavaScript, through the Visual Studio.
- Notification Services that enables the user to generate emails with very little effort.
- Microsoft Integration Services SQL used to integrate data from different data sources. It uses the ETL capabilities. The Integration Services include GUI tools to build the various data streams functions such as export of data from various sources, the transformation of the data including the assembly, and the doubling of the merging.

3.1.3 FMMIS application development

The FMMIS was designed and developed to effectively manage the large amount of data generated and to perform visualization, planning and monitoring. The main functions envisaged were: real time data transfer, logging, mapping, alerting, operations management, planning, financing, reporting and traceability. Through its Graphical User Interface (GUI), users could configure the display and visualize data with the use of maps, gauges, charts and diagrams. The application contains a web-based GIS platform, which can be connected with external mapping services (e.g. Google Maps), and was used for the spatial analysis of the data and the creation of interpolated maps. All the data can be exported to various formats, such as: Vector format (e.g. Shape files, AutoCAD DXF, KML, GeoJSON files), Image format (e.g. BMP, JPG), tabular data format (e.g. XLS, CSV), etc., for further processing from external applications and tools.

The application of the FMMIS was built in C#, which is a programming language that is designed for constructing applications that run on the .NET Framework. C# is an object-oriented language, but also includes support for component-oriented programming. The FMMIS application was developed using HTML5 markup language and CSS3 styling and the responsive web design (RWB) of the FMMIS theme, which is automatically adjusts to different screen sizes, allows to be easily viewable and workable at any device or screen resolution.

.NET framework 4.5 was used (**Figure 16**) because it provides a comprehensive and consistent programming model. Its base class library provides user interface, data access, database connectivity, cryptography, web application development, numeric algorithms, and network communications. The main .NET components that were used for the development of the web application of the FMIS are:

- ASP.NET web forms for making the Graphical User Interface of the website (GUI).
- ADO.NET for accessing and modifying data stored at the FMMIS database systems.
- XML web services for reading the XML data files.
- .NET Remoting which allows the data to be available to many sources.
- AJAX.NET for updating portions of the FMMIS pages without reloading it
- ASP.Net Chart Controls for creating FMMIS charts.

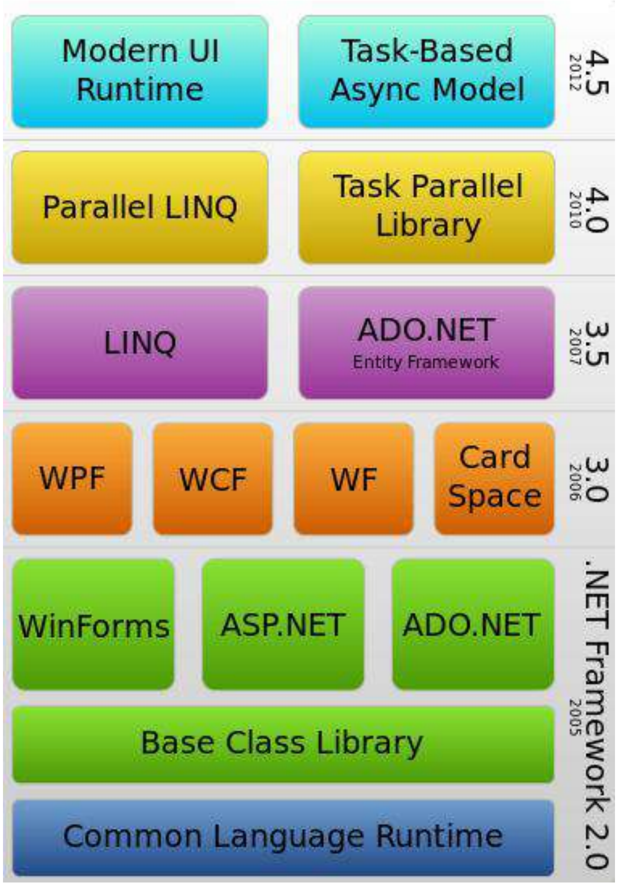


Figure 16: NET Framework 4.5 Architecture (Source: microsoft.com)

The FMMIS is using a responsive design, for making it compatible with any type of device (desktop, mobile phones, tablets etc.) and in order to be user friendly is using a theme which is similar to windows 10 and windows 11 operating systems. The main page of the FMMIS web application is shown in **Figure 17**, while the main user interface is shown in **Figure 18**.

Paging, sorting, filtering, editing, grouping and hierarchy with desktop-like performance.

Lightweight, friendly menu navigation, flexible and easy-to-use.

Figure 17: Main page

FMMIS Home page

FMIS is providing secure and fast browsing

Notifications

11.24°C
Larisa
GR
overcast clouds

Weather

Contact us

FMIS can connect to various sensors

Figure 18: Main user interface

One of the most important modules of the FMMIS is the Cartography module, as the FMMIS is a system used for applying also precision agriculture techniques, in which mapping is a key element. For the maps creation Google Maps API is used as background. The developed FMMIS supports all types of GIS vector features which are: points (**Figure 19**), lines (**Figure 20**), and polygons (**Figure 21**).

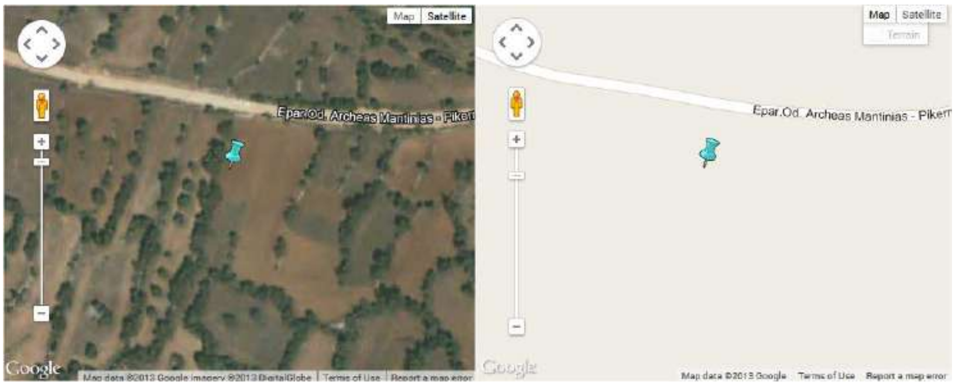


Figure 19: Point vector feature

Figure 20: Line vector feature

Figure 21: Polygon vector feature

For achieving effective and recognizable map visualization, different vector features can be used combined in the same maps using custom icons. **Figure 22** shows the trees and the boundaries of an apple orchard.

Figure 22: Orchard projection

Moreover, FMMIS supports the creation of various types of spatial maps for representing its data in an efficient for the user manner. These include:

- **Heat Maps** (**Figure 23**), where values are depicted by color, making it easy to visualize complex data and understand it at a glance
- **Points Classification** (**Figure 24**), which is he process of sorting or arranging point entities into groups or categories
- **Polygon Classification** (**Figure 25**), which is he process of sorting or arranging polygon entities into groups or categories
- **Spatial interpolation of points** (IDW and kriging) (**Figure 26**), which is the process of using points with known values to estimate values at other unknown points

Figure 23: Heat map

Figure 24: Points classification

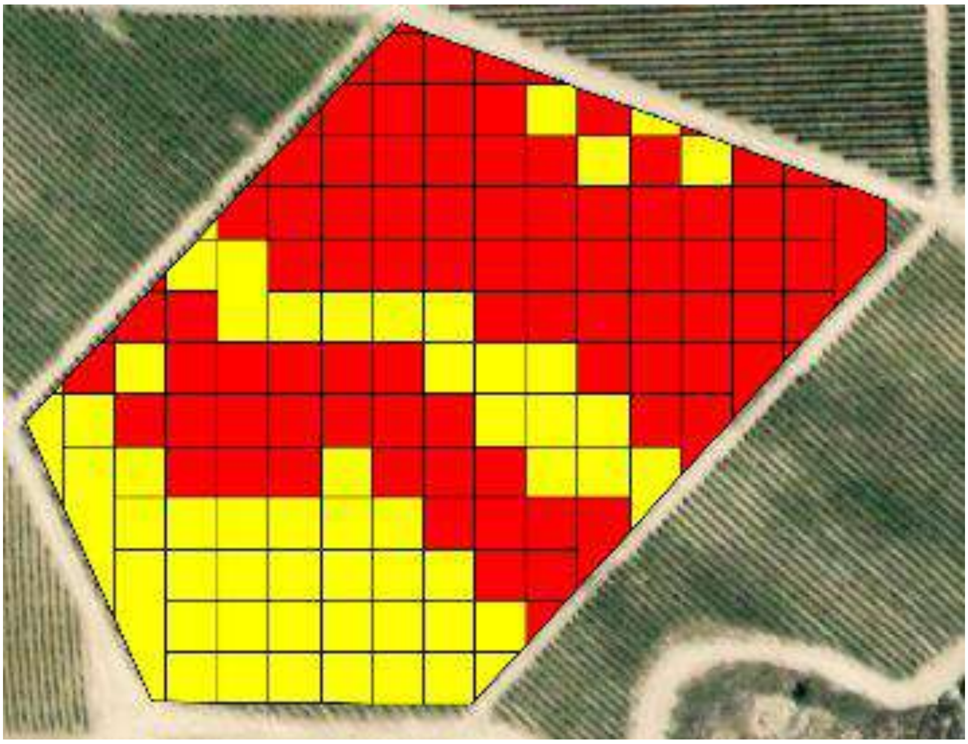


Figure 25: Polygons classification

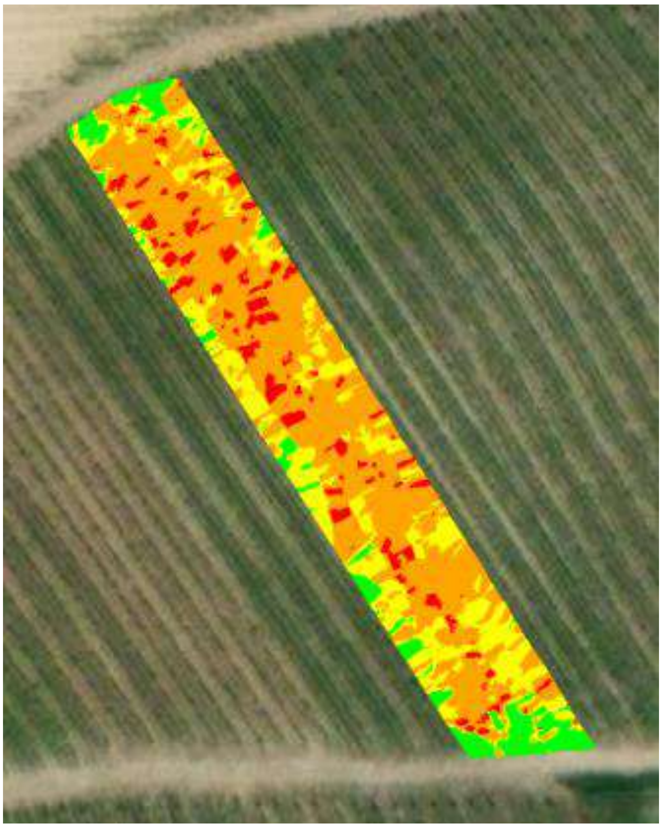


Figure 26: Spatial interpolation of points

All maps can be viewed using different classification methods (e.g. quantile and equal interval as shown in **Figure 27**) and by changing the number of the classes from 2 to 50 depending the user needs (**Figure 28**).

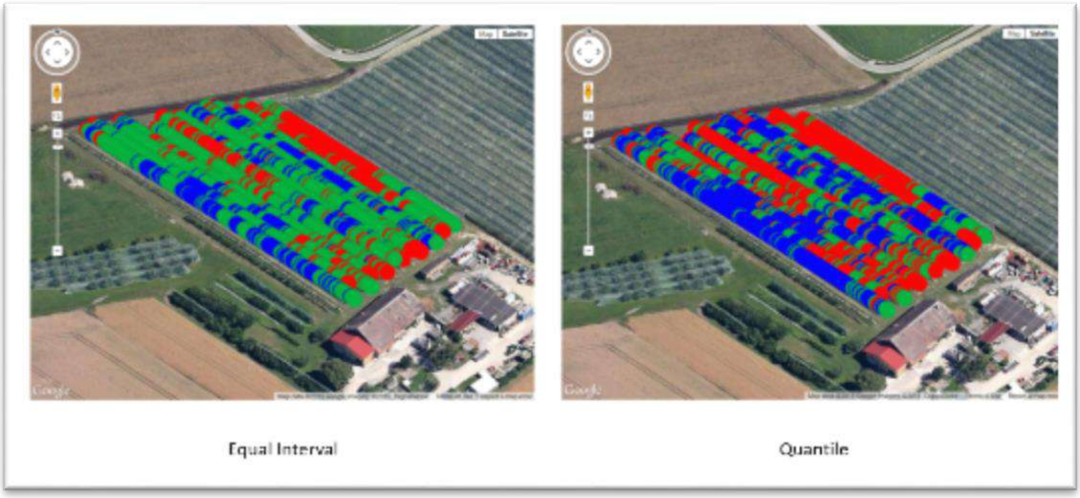


Figure 27: Different classification methods

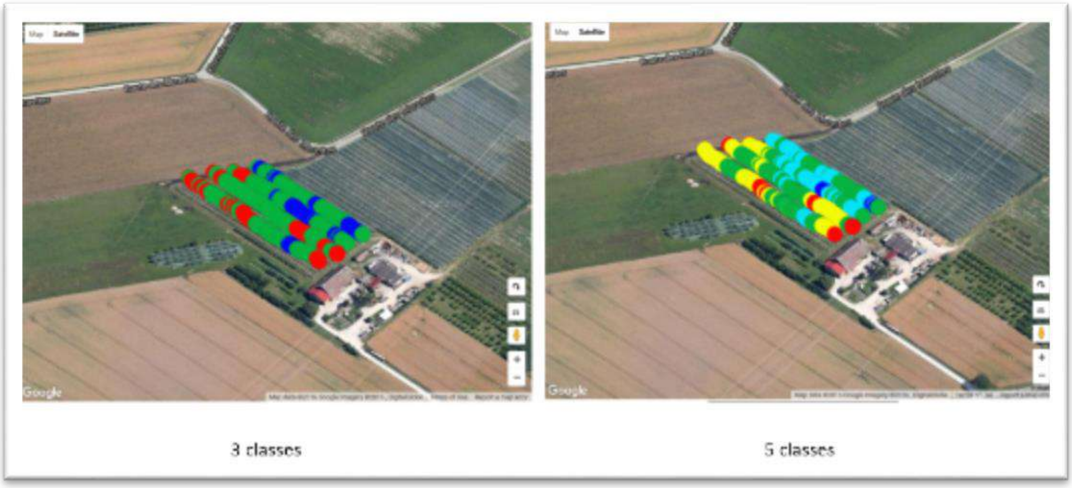


Figure 28: Different number of classes

In addition, the FMMIS can handle the classification and analysis of big data sets as new agricultural technologies create a vast amount of data (**Figure 29**).

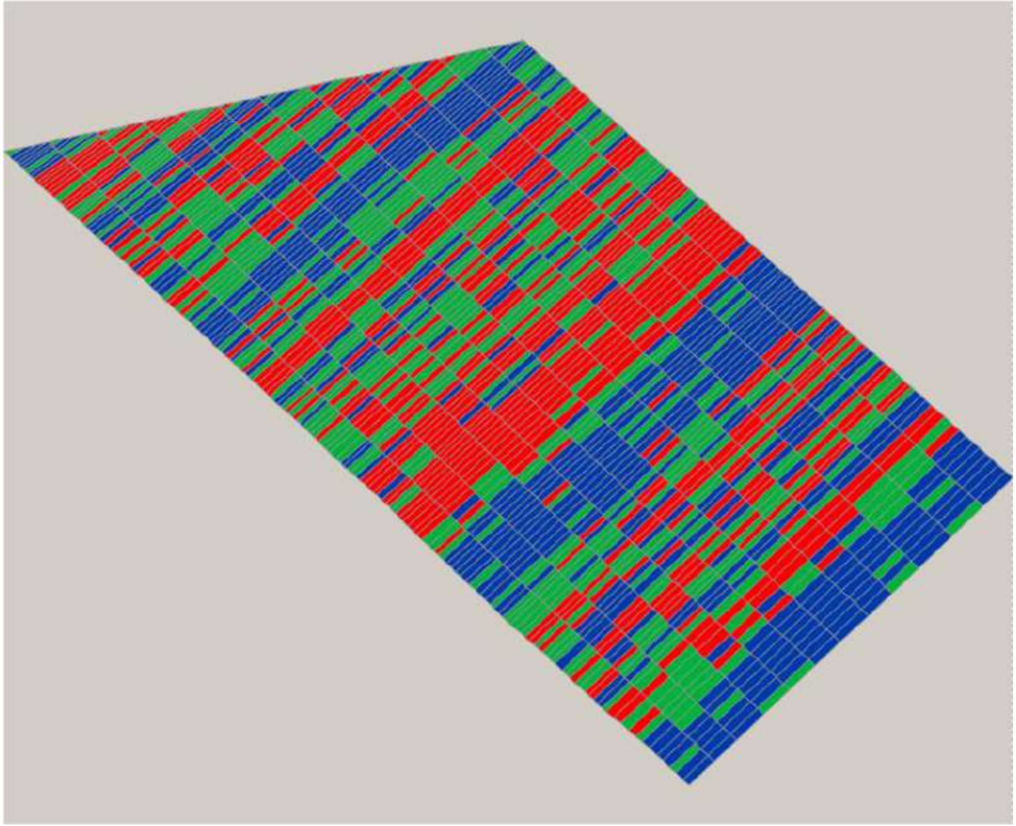
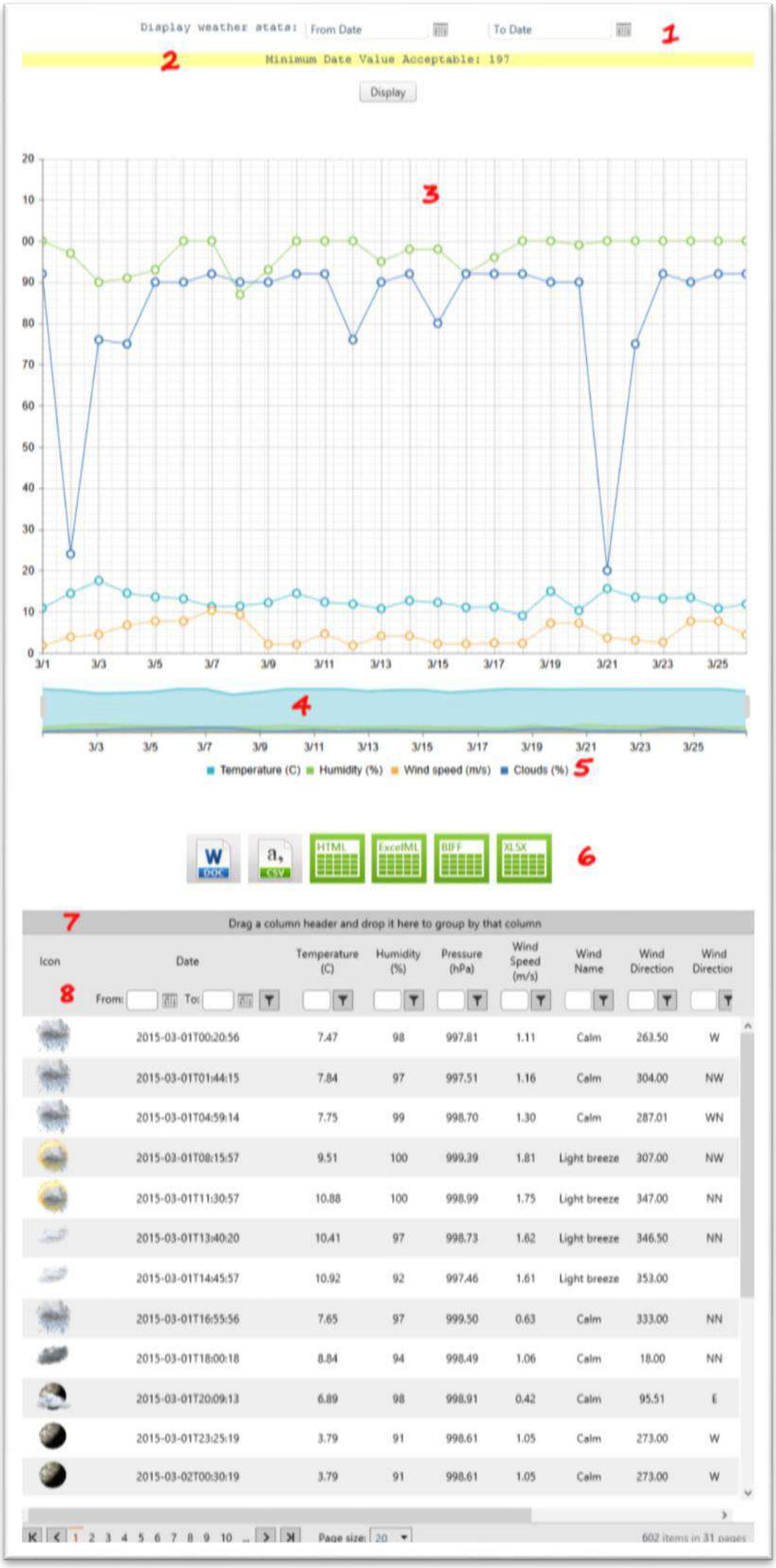


Figure 29: Classification of 2000 polygon shape file

As mentioned before, the FMMIS can display data from various types of sources as sensors or services. All the data can be projected using the same principles and for the needs of this thesis, the data from weather stations are displayed. The FMMIS automatically recognizes and displays the data stored in the database in an easy and functional way giving many options to end users. **Figure 30** displays the page where the user can view the historical data of the weather in the area where the farm is being held.



Icon	Date	Temperature (C)	Humidity (%)	Pressure (hPa)	Wind Speed (m/s)	Wind Name	Wind Direction	Wind Directio
	2015-03-01T00:20:56	7.47	98	997.81	1.11	Calm	263.50	W
	2015-03-01T01:44:15	7.84	97	997.51	1.16	Calm	304.00	NW
	2015-03-01T04:59:14	7.75	99	998.70	1.30	Calm	287.01	WN
	2015-03-01T08:15:57	9.51	100	999.39	1.81	Light breeze	307.00	NW
	2015-03-01T11:30:57	10.88	100	998.99	1.75	Light breeze	347.00	NN
	2015-03-01T13:40:20	10.41	97	998.73	1.62	Light breeze	346.50	NN
	2015-03-01T14:45:57	10.92	92	997.46	1.61	Light breeze	353.00	
	2015-03-01T16:55:56	7.65	97	999.50	0.63	Calm	333.00	NN
	2015-03-01T18:00:18	8.84	94	998.49	1.06	Calm	18.00	NN
	2015-03-01T20:09:13	6.89	98	998.91	0.42	Calm	95.51	E
	2015-03-01T23:25:19	3.79	91	998.61	1.05	Calm	273.00	W
	2015-03-02T00:30:19	3.79	91	998.61	1.05	Calm	273.00	W

Figure 30: Data projection in form of charts and tables

Below the explanation of each figure number displayed in **Figure 30** is given:

1. Data projection in selected period of time
2. System notification with animated text
3. Dynamic chart. Using the mouse wheel, the user can zoom in the graph for larger data analysis.
4. Bar for selecting the desired dates by changing the boundaries of the bar.
5. By clicking the mouse pointer in a measurement name at the chart legend, a measurement can appear or disappear from the chart
6. Data export in different formats (doc, csv, xls) for processing them with other tools and systems.
7. Data Display Table. Users can sort the data by clicking on the name of the field who wish to perform the classification. Also, through the table users can edit or delete data.
8. Data filtering. For example, the user may choose to see only the records in which the temperature was below 0°C.

Moreover, data can be projected using different type of charts for better analysis of the data. **Figure 31** shows the minimum and maximum weather values per each date.

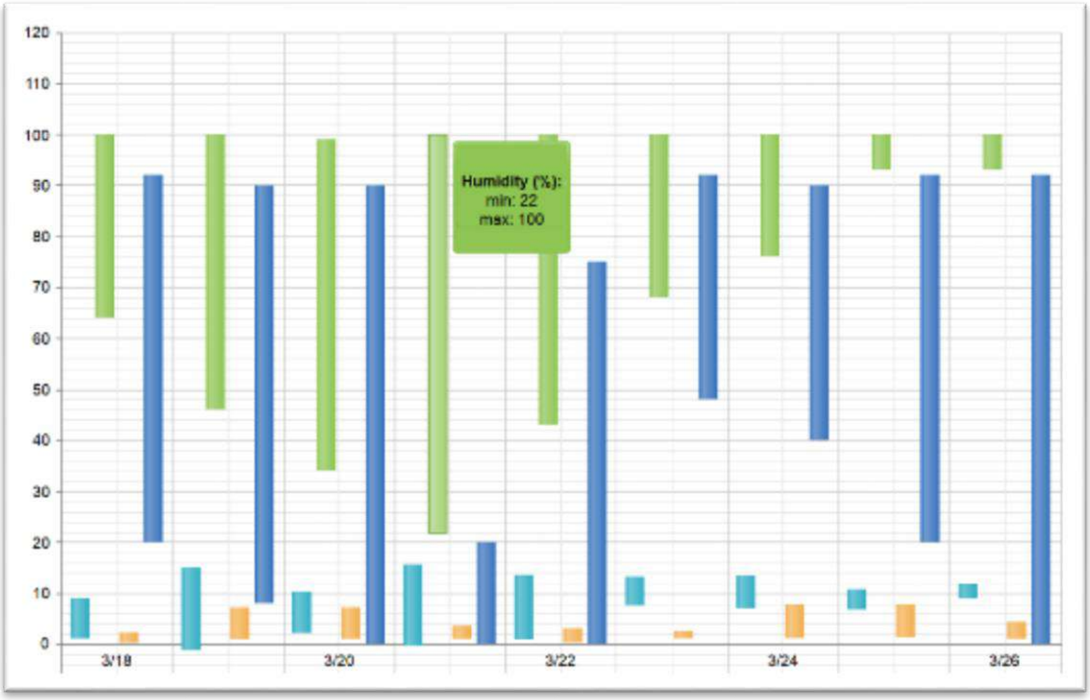
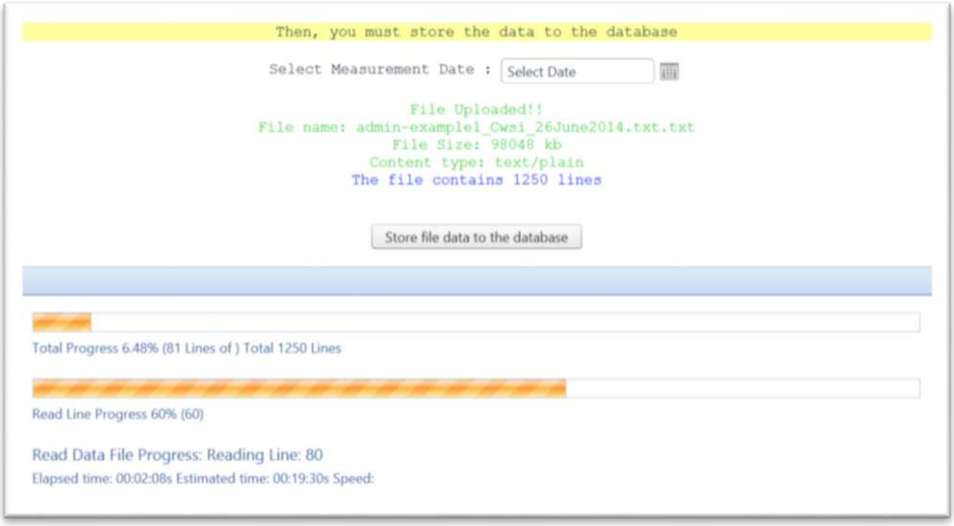


Figure 31: Minimum and maximum values projection

Additionally, the FMMIS support telematics and can project operational data in real time. **Figure 32** shows real time data taken from a Lamborghini R6.130 tractor.

Figure 32: Real time data projection (telematics) from a tractor

Another capability of the FMMIS is the support of sensors that are not supporting real time data transfer or data transfer through web services or an API. For enabling this, the user has to upload the sensor log file and the FMMIS understands the type of data and displays progress bars that inform about the process of importing data to the database and the remaining time (**Figure 33**).



Then, you must store the data to the database

File Uploaded!!
File name: admin-example1_Cwsi_26June2014.txt.txt
File Size: 98048 kb
Content type: text/plain
The file contains 1250 lines

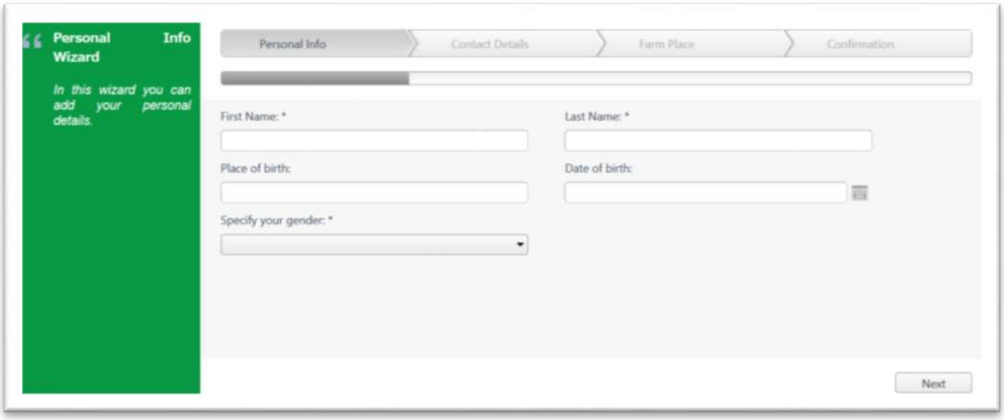
Total Progress 6.48% (81 Lines of) Total 1250 Lines

Read Line Progress 60% (60)

Read Data File Progress: Reading Line: 80
Elapsed time: 00:02:08s Estimated time: 00:19:30s Speed:

Figure 33: Data uploading and storing to the database

For easy learning and usage of the FMMIS, the application has guides and wizards which guide the user during the various operations. **Figure 34** displays the new user registration guide.



Personal Info Wizard

In this wizard you can add your personal details.

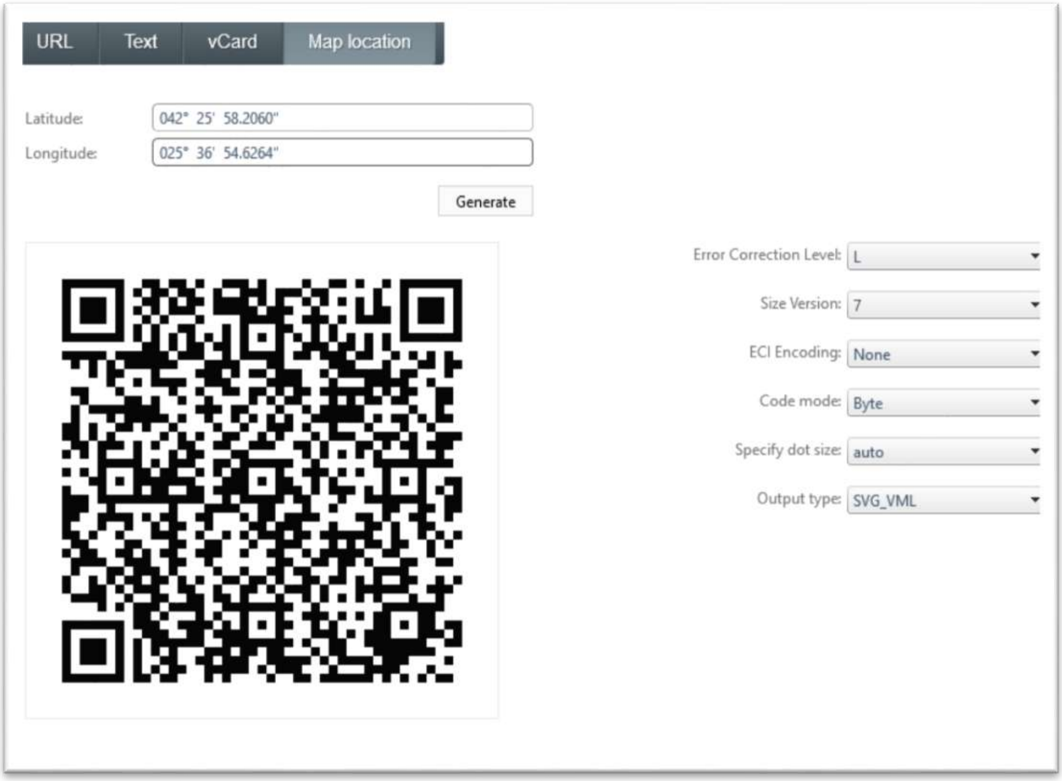
Figure 34: New user registration wizard

Through the capability of applying real-time data analysis, real-time alerts can be generated when some or all of some conditions satisfy predetermined conditions. In this case, the system sends notification to the users via e-mail, SMS, and message alerts within the application (**Figure 35**) in real time.

Low temperature at Greenhouse

Figure 35: Warning in real time into the application environment

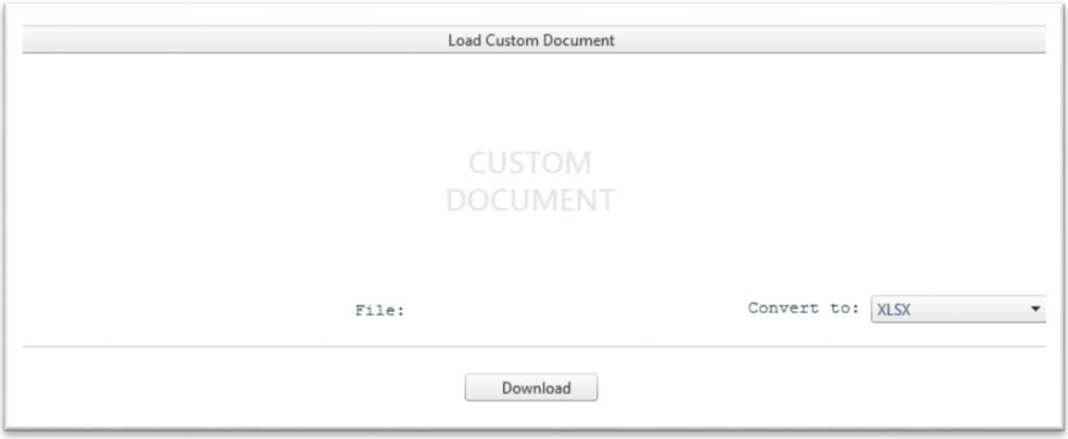
In addition, some extra capabilities have been added to the FMMIS for better serving users such as QR code creator (**Figure 36**), file converter (**Figure 37**), etc.



Latitude: 042° 25' 58.2060"
Longitude: 025° 36' 54.6264"

Error Correction Level: L
Size Version: 7
ECI Encoding: None
Code mode: Byte
Specify dot size: auto
Output type: SVG_VML

Figure 36: QR code creator



File:
Convert to: XLSX

Figure 37: File converter

All the aforementioned FMMIS visualization functionalities, are used from the various FMMIS modules for projecting the data to the end users in a friendly and understandable way.

Finally, the FMMIS has additional capabilities, for better user experience. For example, the users for better data management and data projection, can create custom pages (**Figure 38**) by selecting the specific data they want to be presented (e.g. graphs, tables, maps, measurements etc.). Users can also change the home page by placing tiles with very basic information such as weather, alarms etc.

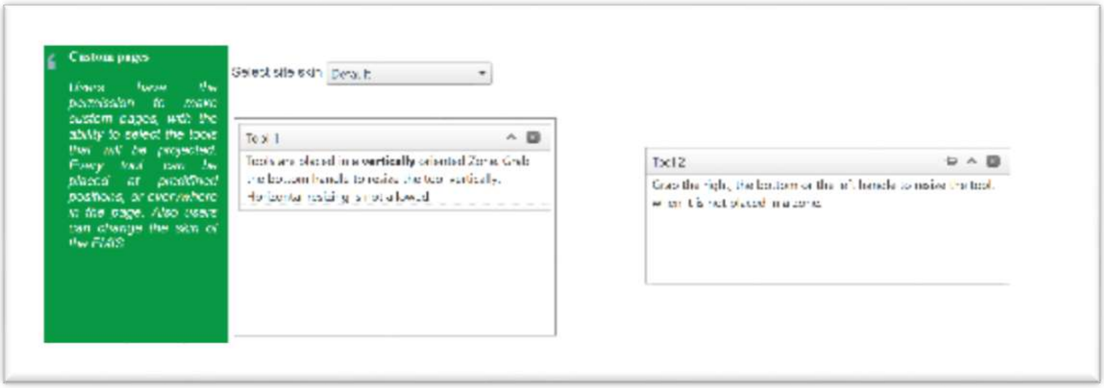


Figure 38: Custom page creation

3.2 Spatial analysis of tractor–implement draft forces for reduced fuel consumption and increased efficiency without affecting tillage depth

3.2.1 Introduction

One application of FMMIS is to assess the functioning of farm machinery. One application that was tested was the verification of the potential to reduce fuel consumption by reducing the engine speed and increase tractor gear during tillage operations.

Tillage constitutes one the most early-exercised agricultural practices. Tillage has been and will always be inseparable to crop production from the time that agriculture was first developed (**Figure 39**). Although that lately ideas like No Till were put forward, still tillage remains the main farming activity in most part of the world. Existing evidence indicate that tillage was performed in the valleys of Euphrates and Nile rivers since 3000 B.C[141].

Figure 39: Tillage in Ancient Egypt (1200 BC)

First tillage applications were manually performed with the use of animals. However, the technological process made during the 20th century allowed the use of fuel engine vehicles/tractors for exercising the agricultural practices.

High yields are associated with well tilled soil, providing a proper environment for seeds to germinate and roots to grow. In addition, tillage can further prepare a seedbed, control weeds, disrupt pest lifecycles, incorporate nutrients and manage crop residues. Of all farm management practices, tillage may have the greatest impact on the environment. Tillage affects the efficiency of cropping inputs such as fertilizer and pesticides, the uptake of soil water and its transpiration, soil biophysical properties and processes, greenhouse gas emissions, etc (Lobb et al. 2007)[142].

Tillage quality is crucial to the success of the complete cropping cycle. A tillage optimization system therefore must assure best working quality under all circumstances, as tillage serves to create suitable growing conditions and secure sustainable soil fertility (Brunotte et al, 2001)[143].

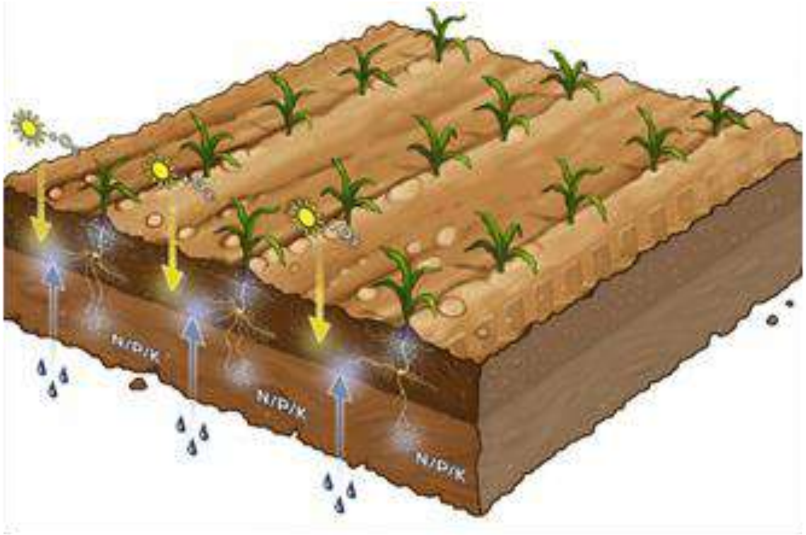


Figure 40: Crops need excellent access to soil moisture. The correct seedbed preparation decides about the successful germination. Figure: Bednar-Machinery (2016)

Soil covering by crops influences: crop yield development, load bearing capacity of soil (reduce compaction), and ground cover capacity (avoid ground erosion). Scholten (2015)[144] cited the German Federal Soil Protection Act (BBodSchG) §17 of Good Agricultural Practice: “The principles of good practice in agricultural soil use are the permanent protection of the soil's fertility and of the soil's functional capacity as a natural resource“. St. John et al (2011)[145] stated that seeds require water, oxygen and heat to germinate, while proper seed needs soil contact for successful germination. Seeds must to be placed neither too deep or nor too shallow, the soil must be firm without harmful compaction. For conventional or clean tillage, the final seedbed needs to be firm enough to leave human footprints less than 1.5 cm deep, the firmer the seedbed, the better.

On the contrary, tillage operations which are not compatible with the requirements of the natural resources could lead to soil degradation or erosion (Friedrich 2006)[146]. Best management practices must therefore be applied and working quality must be monitored during tillage operations.

From the early 80s with the development of microcomputers, the first attempts to record tractor performance data were started by measuring draft forces, velocity, fuel consumption, engine load and wheel slip values (Harter & Kaufman, 1979[147]; Grevis-James et al., 1983[148]). Implement forces are related to tillage depth and apart from the draft forces that are commonly used to determine tillage depth, Knechtges et al. (2010)[149] also pointed out the importance of vertical forces. Tillage depth significantly affects yield and soil strength and high yields are associated with well tilled soil at soil depths to disrupt compacted soil in combination with a cover crop (Raper et al., 2000)[150]. In 1999, ASAE stated[151] that the typical draft requirements could be calculated taking into account the soil texture, implement width, working depth and velocity. The German agricultural society (DLG) test center for agricultural machinery determines the working quality for tillage equipment by evaluating draft forces, ground speed and fuel consumption, working depth and soil surface profile (laser sensor before and after tillage and tool tip horizon by removing tilled soil), aggregated size distribution of tilled soil (sieve test of soil samples), bulk density of topsoil, burrowing of residues (straw) into the topsoil and residue cover.

Tillage, especially ploughing, is the most energy consuming field operation and therefore, sometimes exceeds 50% of the total fuel consumption during a growing season (FAO - Food & Agriculture Organization of the United Nations, 2000)[152]. In the 1970s and 1980s, there were many studies concerning the cost of tillage operations and the analysis of the factors that affects it. The factors mostly examined were tractor velocity, soil properties and implement working depth and width. Zoz (1973)[153] studied the optimum width and velocity to optimize tillage costs. The use of moldboard and chisel plows has attracted the majority of studies for fuel requirements according to different soil conditions (Schrock et al., 1985[154]; Bowers, 1989[155]). In recent years, some research has been conducted on reducing fuel consumption in tillage operations with prediction models (Mehta et al., 2011[156]), at variable depth or site-specific tillage (Bertocco et al.,2008[157]), as well as comparing different tillage practices from conventional to no-till (West & Marland, 2002[158]; Derpsch, 2003[159]).

With the recent increases in fuel costs, producers are searching ways to minimize costs and to increase productivity. Fuel efficiency of agricultural traction works is still only 15 % (Ludwig et al, 2011)[160]. The losses are composed of heat and friction losses of the tractor, rolling resistance on the field and road, tire slip during field operations, bulldozing and compacting the soil. The fact, that tillage is the most energy and, therefore, most costly field operation combined with the need of farmers to increase their profit margins and the societal request for a more environmentally sustainable agriculture, leads farmers to search for alternative tillage practices for reducing fuel consumption and CO_2 emissions of tillage operations. In the recent years it has been proven that tractor driving strategy has more influence on fuel consumption (l/h) than the soil tillage system and that tillage lowers the amount of nitrous oxide (N_2O) released into the atmosphere per hectare compared to no-till practices by up to 66% percent[161]. This is significant, as it is not well known that nitrous oxide is one of the most potent greenhouse gases, trapping up to 300 times more heat that carbon dioxide.

As farmers are seeking ways to reduce their fuel consumption during field operations, auto-guidance systems (GNSS guidance and auto steering systems) have gained increasing interest among farmers to enable farm machinery to follow straight lines to reduce overlaps of the tractor and equipment passes. These systems cost approximately 2500-15000€[162] and help farmers to reduce fuel consumption 6.32% and 5.33% respectively[163]. These systems have been highly appreciated by farmers and the adoption rates has reached more than 15% in large machinery for autosteering, where steering aids (auto-pilot) come close to 100% of the sales.

Gear-up throttle-down (GUTD) is a method of operating a farm tractor at an engine speed less than rated, and improves engine efficiency by maintaining high engine load and engine speed in the range of 60 to 80% of rated speed (Grogan et al., 1987)[164]. Studies have shown that the potential saving of diesel fuel was up to 20%, performing the GUTD technique (Schrock et al., 1982[165]; Chancellor and Thai, 1984[166]). Nevertheless, proper application of GUTD demands good tractor operator experience to sense the minimum specific fuel consumption zone for a particular load and to select the correct gear accordingly to maintain high work rate (Mondal and Rao, 2005)[167].

The ability to monitor and collect tractor and implement performance data can benefit management decisions and lead to fuel savings, which could be achieved through a targeted information management toolkit. A vast amount of data is generated through the current intensive agricultural operations and such an information management toolkit can assist in managing these big data sets for making better decisions at farm level (Fountas et al., 2006)[168]. Nowadays, detailed description of the farm operations and data acquisition of tractor and implement working parameters have been enabled through the agricultural machinery industry protocols SAE J1939 (Society of Automotive Engineers, 1995)[169] and ISO 11783 or ISOBUS (International Organization for Standardization, 1997)[170]. These protocols have been of considerable importance in the development of precision agriculture so that information can be exchanged and stored more efficiently between sensors, processors, controllers and software packages from different manufacturers within the same tractor and/or vehicle (Stafford, 2000)[171].

As explained above, despite a significant amount of research has been carried out on estimating fuel consumption during tillage operations, there has not been any significant progress on developing prototypes to advise farmers on real-time to alter the driving conditions to minimize fuel consumption and optimize tillage quality. Real time optimization of the tillage operation is still missing in all portfolios of the large farm machinery companies and in the market. One of the main reasons is that current tractors only measure the draft forces through a draft sensor that is mounted on the lower right hitch arm of the 3-point hitch, which is not satisfactory. The aim of this work, was to design and develop a component for the Farm Machinery Management Information System (FMMIS) able to utilize not only the draft forces but also the vertical and the side forces data (**Figure 41**) and generate spatial performance maps. This analysis could be useful for analysing tillage operations on a spatial scale in order to reduce energy consumption and maintain good tillage quality which has to do with correct top link length and level adjustment.

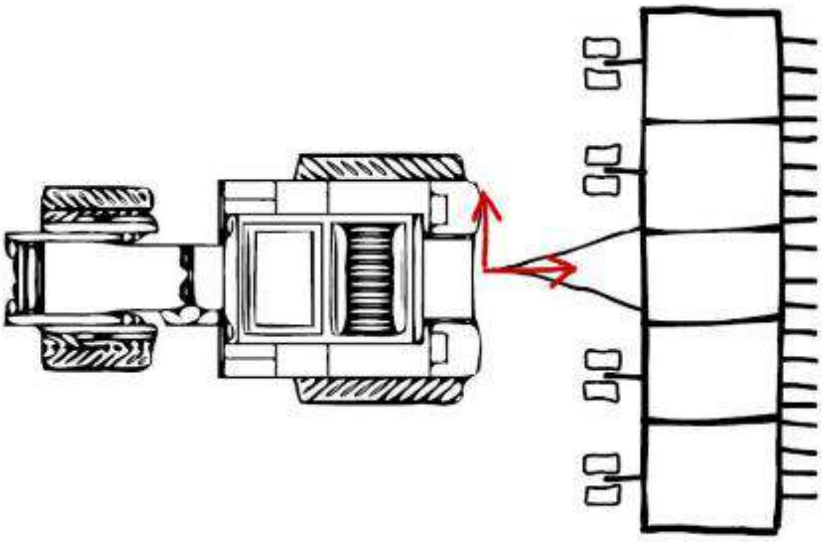


Figure 41: Analysing tillage operations measuring draft, vertical and side forces

3.2.2 Materials and Methods

In total, 2 different force measurement systems (dynamometers) were used. One for measuring the forces on implements attached to the three-point hitch of the tractor and one for measuring the draft forces on implements connected to the tractor drawbar.

3.2.2.1 Three-point hitch instrumented tractor

The dynamometer for measuring forces on implements attached to the three-point hitch of the tractor consisting of six load cells (TSX 2.5, Ados S.r.l., Italy) to measure the forces in three dimensions. Three load cells were horizontal and parallel to the direction of travel to measure draft forces, the other two cells were vertical to measure vertical forces and the sixth was horizontal normal to the direction of travel to measure side forces; together, they measured traction, vertical and side forces (**Figure 42**).

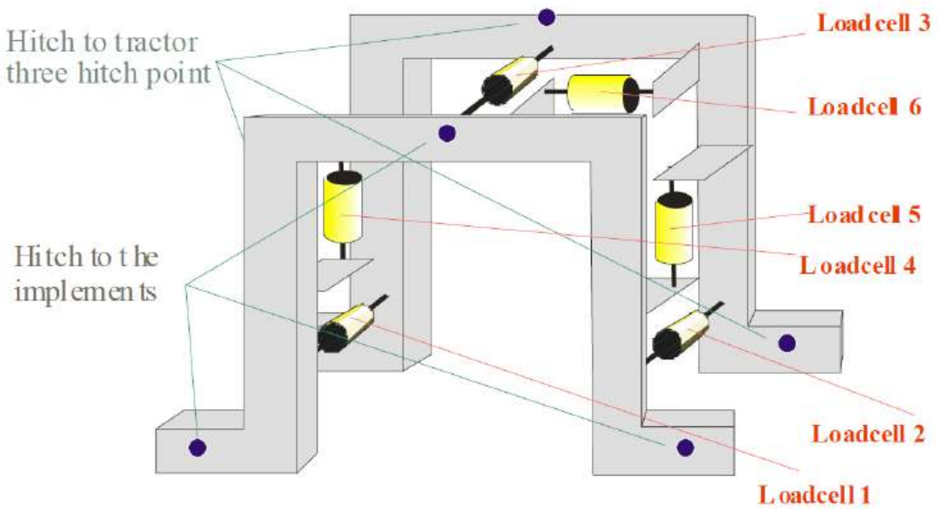


Figure 42: Three-point hitch dynamometer

The load cells were powered by a 13.8V regulated DC power supply (RPS 1206, Samlex Electric Company Limited, Hong Kong, **Figure 43**).

Figure 43: 13.8V regulated DC power supply

Calibration was performed on each loading cell by applying known loads and measuring the output signal in mV. The electrical signals of the load cells were transferred to a 16-bit, 8-channel analog input module (Adam 4017+, Advantech Co. Ltd, USA - **Figure 44**), which converted the signals to a serial communication protocol RS485.

Figure 44: Data Acquisition module

1-port isolated USB to RS-232/422/485 converter was used for the conversion of the RS 485 protocol to USB interface (Adam 4561, Advantech Co. Ltd, USA **- Figure 45**), for retrieving the data using a windows laptop.

Figure 45: USB to RS485 converter

The dynamometer was attached to the three point hitch of the tractor (R6. 130, Lamborghini, Italy **- Figure 46**).

Figure 46: Three-point hitch dynamometer attached to the tractor

Data from the tractor ECU was transferred through SAE J1939 protocol using USB interface. The tractor operating parameters which were fed into the toolkit were: velocity, fuel consumption, engine speed, torque and slip. For recording the position of the tractor–implement combination, a DGPS device (AgGPS-252 Receiver, Trimble Ltd., USA) was installed on the roof of the tractor. The signals from the aforementioned data sources were transferred to a notebook through 3 USB connectors with a sample rate of 4 Hz.

3.2.2.2 Drawbar instrumented tractor

In this configuration, the load cell was attached to the tractor drawbar and consisted of one load cell (**Figure 47**).

Figure 47: Drawbar dynamometer attached to the tractor

The load cell was attached to a Caterpillar Challenger MT765D tractor (Peoria, IL, USA - **Figure 48**) and was powered through Caterpillar (Peoria, IL, USA) PowerLink® which logs the draft forces, the vehicle velocity (through speed radar) and the engine power.

Figure 48: Caterpillar Challenger MT765D tractor

Measurement Computing (Norton, MA, USA) USB-1208LS DAQ device (**Figure 49**) was used for calculating the fuel consumption with an external fuel sensor (for logging fuel sensor pulses) and the position was determined through a Trimble (Sunnyvale, CA, USA) Field-IQ with CFX-750 touch-screen display RTK-GPS.

Figure 49: USB-1208LS DAQ device

As in the previous case, the signals from the aforementioned data sources were transferred to a notebook through USB connectors with a sample rate of 1 Hz.

3.2.2.3 Field experiments

The initial experiments were held at a field at the farm of the former Technological Educational Institute of Larissa, now University of Thessaly, Greece, using a heavy duty rigid type cultivator attached at the three-point hitch dynamometer (**Figure 50**).

Figure 50: Duty rigid type cultivator attached at the three-point hitch dynamometer

These experiments were held for investigating the correlations between the various tractor-implement working parameters, and most importantly the correlation between the draft forces and the engine torque and speed for ensuring that GUTD technique can be used for reducing fuel consumption at tillage operations. Normally, farmers are ploughing at rated engine speed, in which the diesel engines of the tractors are not providing the maximum torque (**Figure 51**) which is needed for overcoming draft forces, and is the basis of using GUTD technique during tillage.

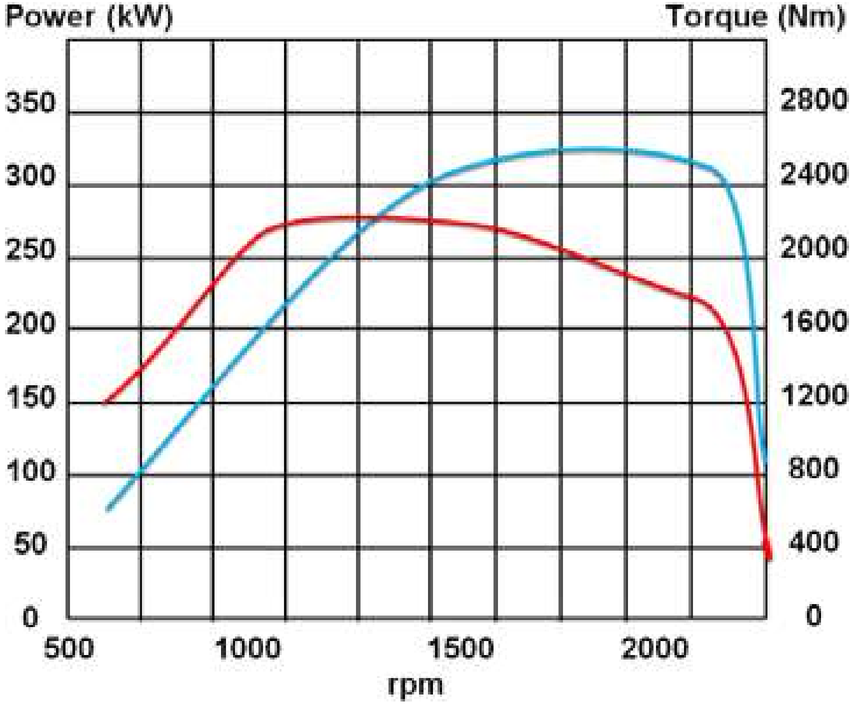


Figure 51: Horsepower (blue line) and torque (red line) in a tractor diesel engine[172]

After, the analysis of the initial results, 2 different experiments were held using the 2 instrumented tractors.

<u>The experiments using the three-point hitch instrumented tractor</u>, were held at a 1.2 ha field (Latitude 39.37°, Longitude 22.22°). The field was divided into 36 plots. 3 different implement were used (duty rigid type cultivator, disc harrow and plough). Each implement was used in 12 plots, each 50m long by 6m wide, at different operating settings of tractor velocity (5, 7 and 9 km/h), engine speed (1800 and 2200 rpm) and working depth (20 and 25cm) (**Table 6** and **Figure 52**). Velocity and working depth were varied in order to analyse their effect on fuel consumption and draft forces. Two engine speeds were selected for analyzing the change in fuel consumption, comparing one value within and one value outside of the ideal 60-80% of maximum speed required for maximum engine efficiency.

Table 6: Various operative examples for each implement

Plot	Engine Speed (rpm)	Velocity (km/h)	Depth (cm)
a	1800	5	20
b	1800	7	20
c	1800	9	20
d	2200	5	20
e	2200	7	20
f	2200	9	20
g	1800	5	25
h	1800	7	25
i	1800	9	25
j	2200	5	25
k	2200	7	25
l	2200	9	25

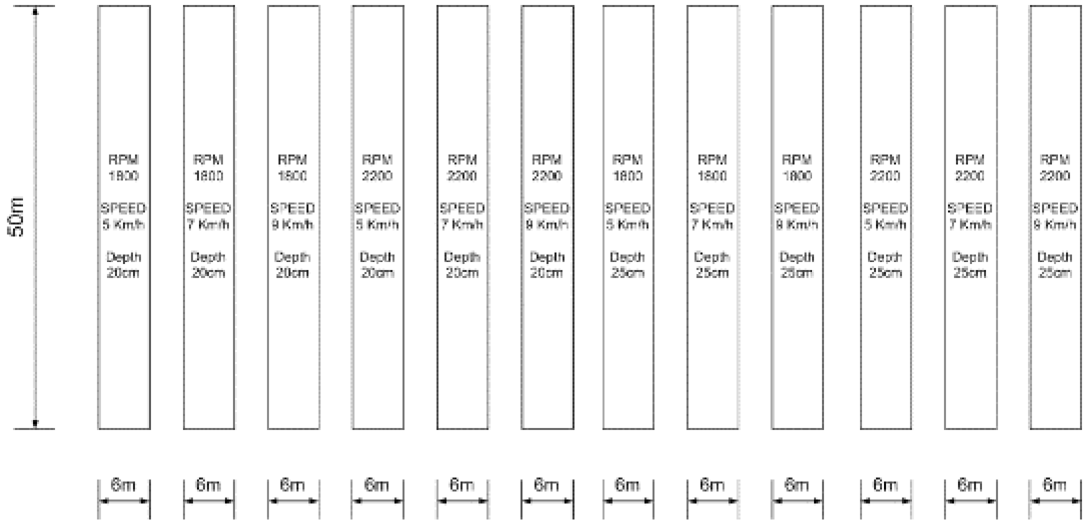


Figure 52: Cultivation using three point hitch dynamometer

The experiments using the drawbar instrumented tractor held at Large March Field of Harper Adams University, Newport, UK (Latitude 52.46° Longitude 2.25). A tracked Cat Challenger MT765D with a 4m Väderstad TopDown cultivated the deep (250mm) and shallow (100mm) tillage plots (**Figure 53**).

Figure 53: Cultivation using drawbar dynamometer

The experiment was a 3x3 factorial design with treatments randomly allocated on plots (n=36) arranged in 4 blocks, as shown in **Figure 54**.

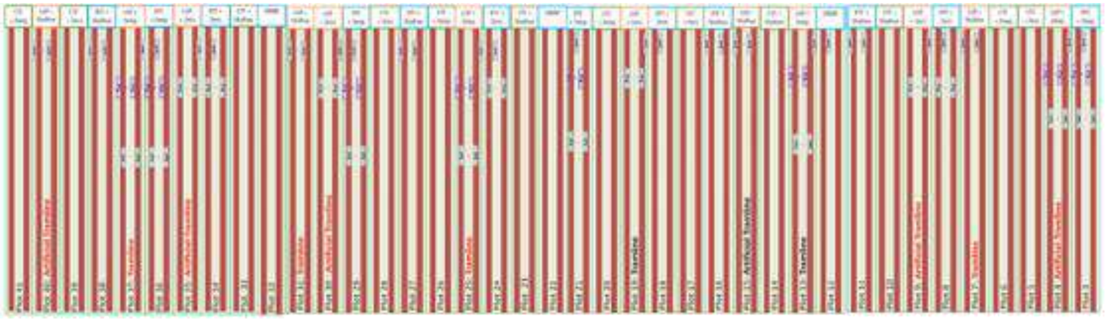


Figure 54: Experimental design

3.2.2.4 Software

For retrieving and storing the data of the field experiments, 2 two different windows-based applications were developed (one application for each different instrumented tractor). The applications were written in C# which is a multi-paradigm programming language encompassing strong typing, imperative, declarative, functional, generic, object-oriented (class-based), and component-oriented programming disciplines. The data was stored locally in csv format at the laptop running the applications. These applications receive and combine in real time, data from three different sources:

- The dynamometer, for measuring implement forces,
- the tractor electronic control unit – ECU, for retrieving tractor’s data
- GPS receiver for recording implement position.

Table 7 below presents the data sources for each instrumented tractor.

Table 7: Data sources in each experiment

Measurement	**Greece**	**UK**	**Data Source**		**Frequency**	
			Greece	UK	Greece	UK
Draft Forces	√	√	Three-point hitch dynamometer (Three load cells horizontal and parallel to the direction of travel)	Tractor drawbar through Caterpillar PowerLink (One load cell horizontal and parallel to the direction of travel)	4 Hz	1 Hz
Vertical forces	√	-	Three-point hitch dynamometer (Two vertical load cells)	-	4 Hz	-
Side forces	√	-	Three-point hitch dynamometer (One load cell horizontal normal to the direction of travel)	-	4 Hz	-
Positioning (RTK – GPS)	√	√	TOPCON Hyper SR RTK-GPS	Trimble Field-IQ with CFX-750 touch-screen displays RTK-GPS	4 Hz	1 Hz
Velocity	√	√	TOPCON Hyper SR RTK-GPS	Trimble Field-IQ with CFX-750 touch-screen displays RTK-GPS	10 Hz	1 Hz
			Tractor ECU	Caterpillar PowerLink	4 Hz	1 Hz
Fuel consumption	√	√	Tractor ECU	Tractor ECU External Fuel Sensor	4 Hz	1 Hz

Measurement	Greece	UK	Data Source		Frequency	
Engine speed (RPM)	√	√	Tractor ECU	Tractor ECU	4 Hz	1 Hz
Torque	√	√	Tractor ECU	Tractor ECU	4 Hz	1 Hz
Slip	√	√	Tractor ECU	Tractor ECU	4 Hz	1 Hz
Engine power	-	√	-	Caterpillar PowerLink	-	1 Hz

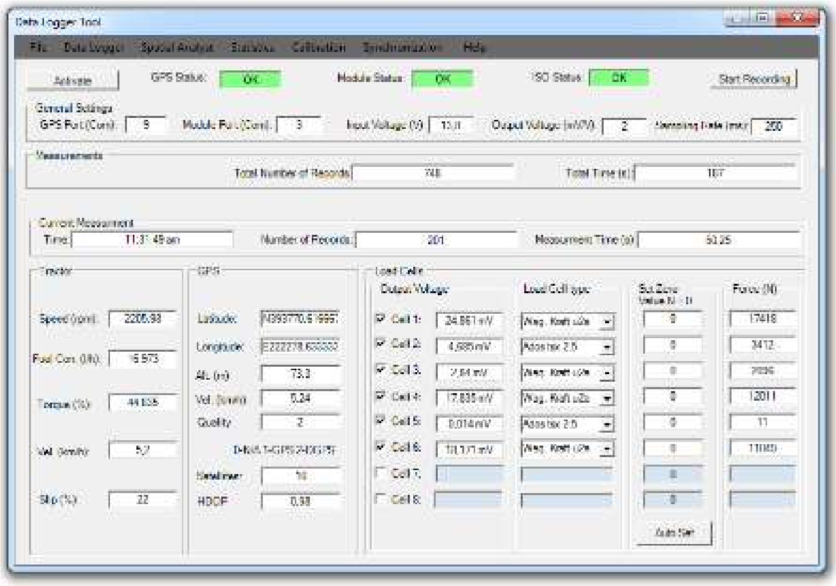
This initial windows-based applications had several capabilities for making the tillage operation data analysis. These were:

- The **Calibration module** for storing load cells calibration data,
- the **Data logger module** for storing the measurements,
- the **Statistics module** where recorded data could be viewed and analyzed, and
- the **Spatial Analyst** for spatial mapping of the data.

At a second stage, and after the analysis of the initial results, a new windows application was developed for the optimization of tillage operations. The data transferring between the windows-based application and the FMMIS was made using an API that was developed for this purpose.

Three-point hitch instrumented tractor software (Greece)

The data monitoring and recording was carried out through the windows-based application (**Figure 55**) that was developed for this reason.



GPS Status: OK
Module Status: OK
ISO Status: OK
Total Number of Records: 748
Total Time (s): 187
Time: 11:31:49 am
Number of Records: 201
Measurement Time (s): 50.25
Speed (rpm): 2205.98
Fuel Con. (l/h): 16.573
Slip (%): 22
Alt. (m): 73.3
Vel. (km/h): 5.24
Quality: 2
HDOP: 0.98

Figure 55: Three-point hitch instrumented tractor data logger

The application had several modules as presented in **Figure 56**.

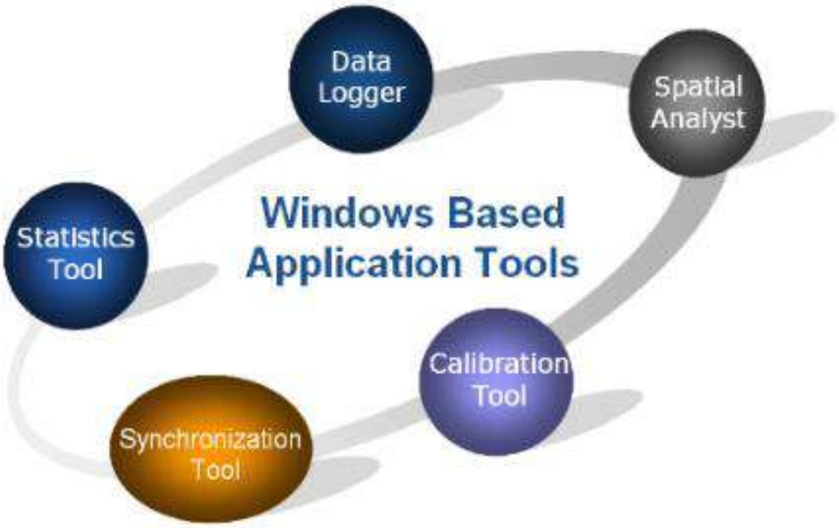
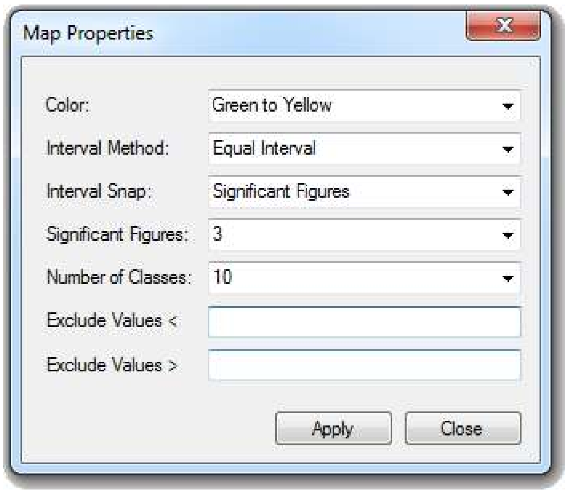


Figure 56: Windows based application modules

At first, user has to set up some basic settings which are the COM ports (for GPS receiver and data acquisition module), the input and the output voltage of the load cells, the sampling rate in milliseconds and the type of each load cell. The types of load cells are available from the **Calibration module** where the calibration of each cell is being stored. The calibration module has the option to choose the number of load cells that will be recorded (up to 8 load cells) and the option to add the rated capacity and the zero value (tare) of each cell. This enables the Data Logger module to be used with a variety of custom made draft force measurement systems or with other measurement systems.

After set-up, the **Data Logger module** displays the values of the data sources in real time. The data can also be stored in the local database using the record button. If there was an active internet connection available and the online synchronization between the windows application and the FMMIS have been activated from the **Synchronization module**, the Data Logger module sends the data, apart from the database of the windows-based application to the FMMIS database, for monitoring remotely in real time the soil treatment activity. Alternatively, synchronization could be done after the tillage operations. Moreover, with the use of the Synchronization module, users have the ability to upload spatial maps to the FMMIS.

The Spatial Analyst module is used for generating spatial maps where the interpolation is done using Inverse Distance Weighted (IDW) method which estimates cell values by averaging the values of sample data points in the neighborhood of each processing cell. The default values for the interpolation are: power parameter p is 2 (p = 2) which is known as the inverse distance squared weighted interpolation, number of neighbours is 12 and classification type is Equal Interval. The option of changing the interpolation default values is available before starting the interpolation process. Moreover, after the interpolation, many options are given for the representation of the spatial data into a map (**Figure 57**, **Figure 58**). These include: Interval Method selection (equal interval, quantile, manual), Interval Snap selection (data value, rounding, significant figures, none), Number of classes selection (up to 100), Excluded Values set-up, Colours selection etc.



Color: Green to Yellow
Interval Method: Equal Interval
Interval Snap: Significant Figures
Significant Figures: 3
Number of Classes: 10
Exclude Values <
Exclude Values >

Figure 57: Map properties

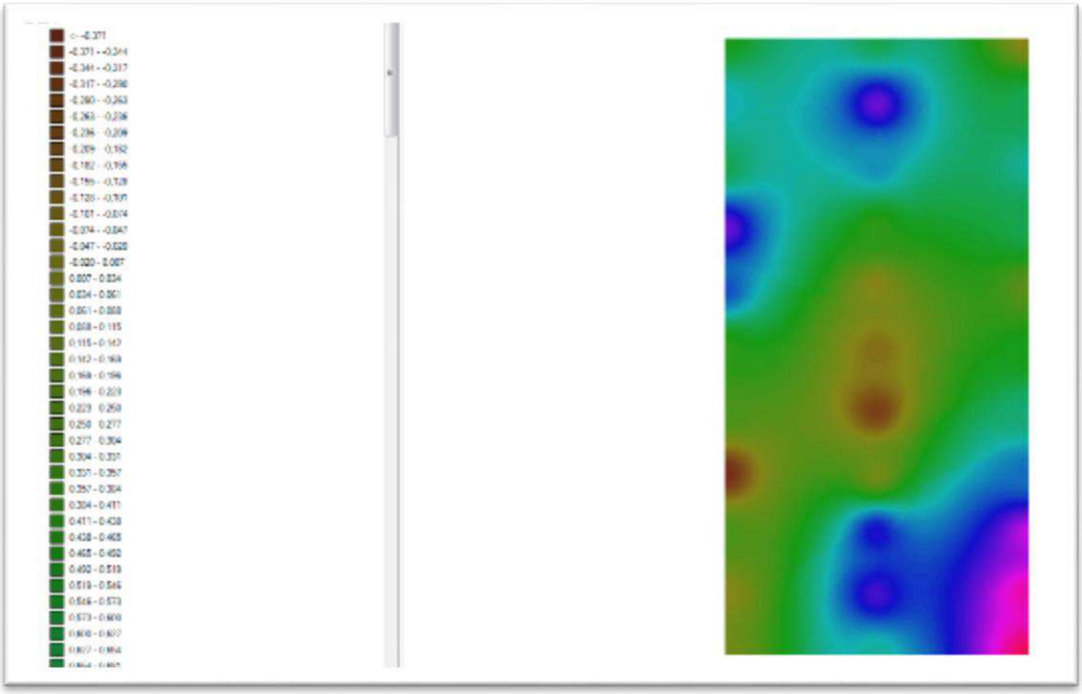


Figure 58: Map created from the spatial analyst module

The **Statistics Module** can be used to generate charts and tables from the recorded data. From the module a large number of predefined charts can be selected.

Drawbar instrumented tractor software (UK)

For the drawbar instrumented tractor, the data monitoring and recording was also made through a windows-based application that was developed for this research that was called Cat-log from the brand name of the tractor (Caterpillar). A simplified architecture diagram of Cat-log is given in **Figure 59**.

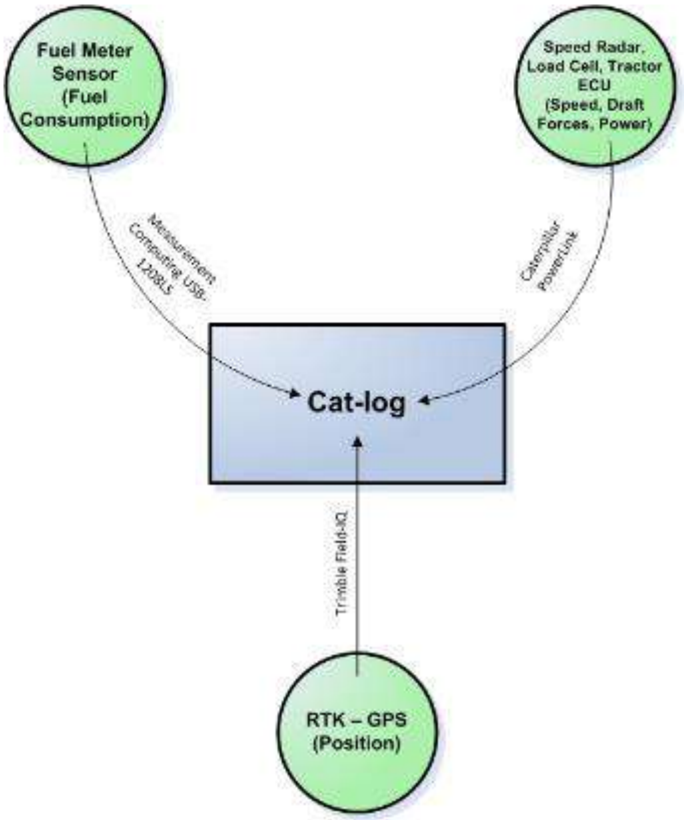


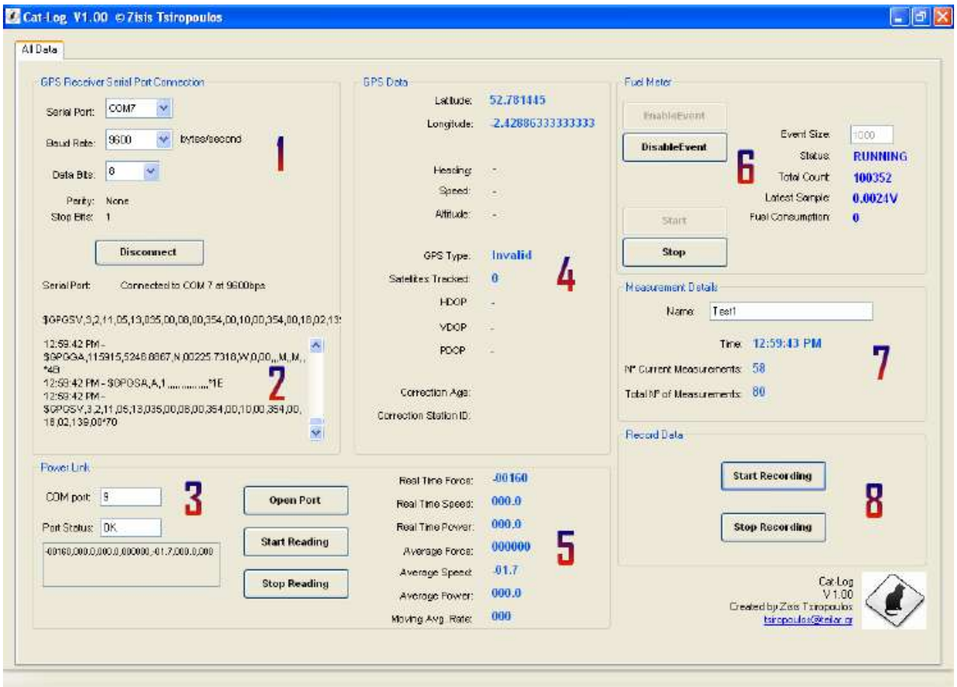
Figure 59: Cat-Log simplified architecture

The application takes simultaneously data from 3 different sources. These sources are:

- **Fuel meter**: Measurement of fuel consumption. The connection is being made through DAQ Measurement Computing USB-1208LS
- **Caterpillar powerlink**: Measurements of Draft Forces, Speed, and tractor power
- **RTK – GPS**: Positioning of the tractor and its implement

All logged data were being recorded in a Microsoft Access Database file (*.mdb), for being easily readable and editable. The frequency of data storing in cat-log database was 1Hz, and depends on the slowest component which is Caterpillar powerlink, which gives new values every 1 second.

Cat-log application main screen is shown in **Figure 60**.



Serial Port: COM7
Baud Rate: 9600 bytes/second
Data Bits: 8
Parity: None
Stop Bits: 1
Serial Port: Connected to COM 7 at 9600bps

```
$GPGSV,3,2,11,05,13,035,00,08,00,354,00,10,00,354,00,18,02,13
12:59:42 PM -
$GPGGA,115915,5246.8867,N,00225.7318,W,0,00,,,M,,M,,
*4B
12:59:42 PM - $GPGSA,A,1,,,,,,,,,,,,,,*1E
12:59:42 PM -
$GPGSV,3,2,11,05,13,035,00,08,00,354,00,10,00,354,00,
18,02,139,00*70
```

Latitude: 52.781445
Longitude: -2.42886333333333
Heading: -
Speed: -
Altitude: -
GPS Type: Invalid
Satellites Tracked: 0
HDOP: -
VDOP: -
PDOP: -
Correction Age:
Correction Station ID:

Event Size: 1000
Status: RUNNING
Total Count: 100352
Latest Sample: 0.0024V
Fuel Consumption: 0

Name: Test1
Time: 12:59:43 PM
Nº Current Measurements: 58
Total Nº of Measurements: 80

COM port: 9
Port Status: OK

```
-00160,000.0,000.0,000000,-01.7,000.0,000
```

Real Time Force: -00160
Real Time Speed: 000.0
Real Time Power: 000.0
Average Force: 000000
Average Speed: -01.7
Average Power: 000.0
Moving Avg. Rate: 000

Figure 60: Cat-Log main screen

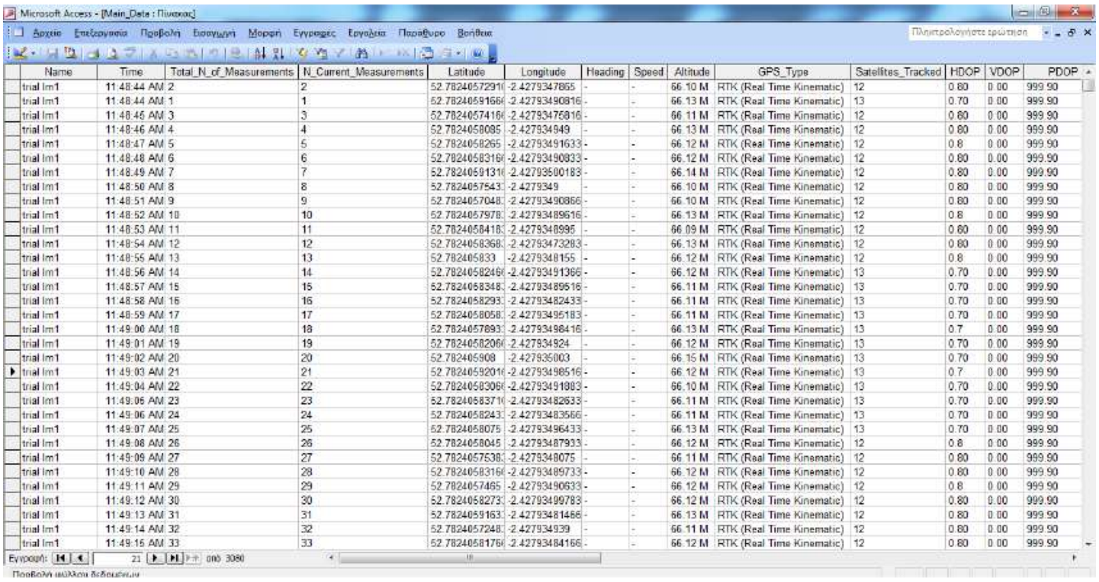
More analytically the numbers in **Figure 60** shows:

1. **GPS Connection Parameters**: Each GPS, DGPS or RTK-GPS is compatible with Cat-log application. From the GPS connection parameters user can set the port and the Baud – Rate of the GPS.
2. **GPS NMEA string**: When GPS is successful connected to the application, the NMEA string protocol appears in that box in real time.
3. **Power Link Connection Parameters**: User types the COM port of the Powerlink device. After the successful connection the box gives the Powerlink string in real time.
4. **GPS Data**: GPS data values are shown.
5. **Powerlink Data**: Powerlink data values are shown.

6. **Fuel Meter**: Connection and fuel consumption data.
7. **Measurement details**: Name of measurement, number of current measurement and total number of measurements.
8. **Record Data**: Start and Stop logging data into application database.

This application was designed with increased flexibility. For that reason, it doesn't need all of 3 sources in order to work. It can work for example only with one source (e.g. GPS) and to be used as a simple GPS logger. It supports every GPS that exports data in NMEA protocol, and the fuel meter function can be used as a pulse counter in any digital or analog sensor or system.

The data are being logged into a Microsoft access database (**Figure 61**). All data are been stored in one table, and they can be exported in various formats as excel files (*.xls), XML files (*.xml) etc.



Name	Time	Total_N_of_Measurements	N_Current_Measurements	Latitude	Longitude	Heading	Speed	Altitude	GPS_Type	Satellites_Tracked	HDOP	VDOP	PDOP
trial lm1	11:48:44 AM	2	2	52.7824057291	-2.4279347865	-	-	66.10 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:44 AM	1	1	52.7824059166	-2.42793490816	-	-	66.13 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:48:45 AM	3	3	52.7824057416	-2.42793475816	-	-	66.11 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:46 AM	4	4	52.7824058085	-2.427934949	-	-	66.13 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:47 AM	5	5	52.7824058265	-2.42793491633	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.8	0.00	999.90
trial lm1	11:48:48 AM	6	6	52.7824058316	-2.42793490833	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:49 AM	7	7	52.7824059131	-2.42793500183	-	-	66.14 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:50 AM	8	8	52.7824057543	-2.4279349	-	-	66.10 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:51 AM	9	9	52.7824057048	-2.42793490866	-	-	66.10 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:52 AM	10	10	52.7824057978	-2.42793489616	-	-	66.13 M	RTK (Real Time Kinematic)	12	0.8	0.00	999.90
trial lm1	11:48:53 AM	11	11	52.7824058418	-2.4279348995	-	-	66.09 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:54 AM	12	12	52.7824058368	-2.42793473283	-	-	66.13 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:48:55 AM	13	13	52.782405833	-2.4279348155	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.8	0.00	999.90
trial lm1	11:48:56 AM	14	14	52.7824058246	-2.42793491366	-	-	66.12 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:48:57 AM	15	15	52.7824058348	-2.42793489516	-	-	66.11 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:48:58 AM	16	16	52.7824058293	-2.42793482433	-	-	66.11 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:48:59 AM	17	17	52.7824058058	-2.42793495183	-	-	66.11 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:00 AM	18	18	52.7824057893	-2.42793498416	-	-	66.13 M	RTK (Real Time Kinematic)	13	0.7	0.00	999.90
trial lm1	11:49:01 AM	19	19	52.7824058206	-2.427934924	-	-	66.12 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:02 AM	20	20	52.782405908	-2.427935003	-	-	66.15 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:03 AM	21	21	52.7824059201	-2.42793498516	-	-	66.12 M	RTK (Real Time Kinematic)	13	0.7	0.00	999.90
trial lm1	11:49:04 AM	22	22	52.7824058306	-2.42793491883	-	-	66.10 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:05 AM	23	23	52.7824058371	-2.42793482633	-	-	66.11 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:06 AM	24	24	52.7824058243	-2.42793483566	-	-	66.11 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:07 AM	25	25	52.7824058075	-2.42793496433	-	-	66.13 M	RTK (Real Time Kinematic)	13	0.70	0.00	999.90
trial lm1	11:49:08 AM	26	26	52.7824058045	-2.42793487933	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.8	0.00	999.90
trial lm1	11:49:09 AM	27	27	52.7824057538	-2.4279348075	-	-	66.11 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:49:10 AM	28	28	52.7824058316	-2.42793489733	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:49:11 AM	29	29	52.7824057465	-2.42793490633	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.8	0.00	999.90
trial lm1	11:49:12 AM	30	30	52.7824058273	-2.42793499783	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:49:13 AM	31	31	52.7824059163	-2.42793481466	-	-	66.13 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:49:14 AM	32	32	52.7824057248	-2.427934939	-	-	66.11 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90
trial lm1	11:49:15 AM	33	33	52.7824058176	-2.42793484166	-	-	66.12 M	RTK (Real Time Kinematic)	12	0.80	0.00	999.90

Figure 61: Cat-Log Database

3.2.3 Results

The correlation between all parameters was proved at the initial experiment, Traction (draft forces) and torque showed similar patterns (**Figure 62**) with working velocity of 5 km/h at 2 different engine speeds (1800 and 2200 rpm) at the same depth using the heavy cultivator. At the same time, the fuel consumption was 20% higher at 2200 rpm compared to 1800 rpm. That results was the proof that the application of GUTD technique can reduce fuel consumption without affecting the forces applied during tillage operation.

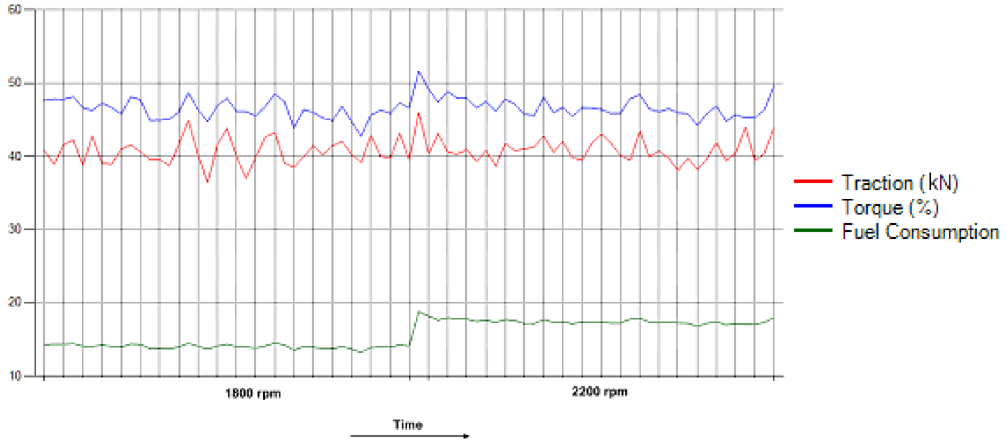


Figure 62: Engine torque, fuel consumption and traction working with velocity of 5km/h at 2 different engine speeds (1800 and 2200 rpm)

After the validation of the initial hypothesis that engine speed affects fuel consumption a set of experiments were held to investigate how implement forces can be used by a FMMIS for reducing fuel consumption, without affecting tillage quality by altering its depth. For this reason, the effect of tillage operation velocity to the implement forces was recorded and analyzed using spatial interpolation (**Figure 63**).

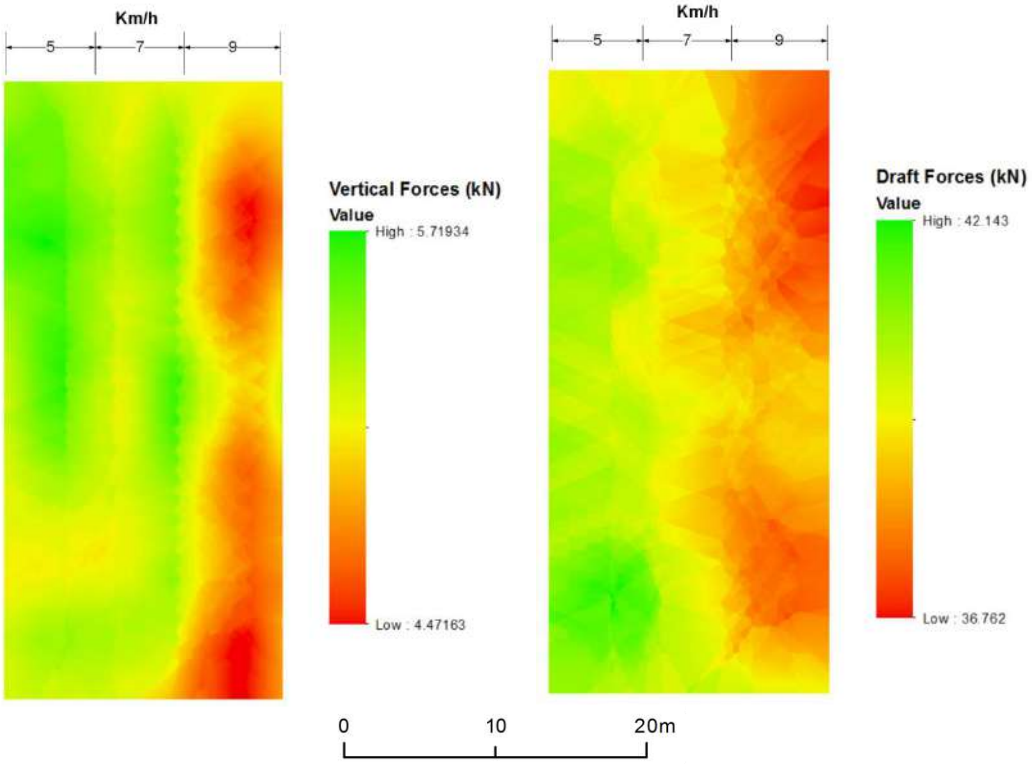


Figure 63: Draft and vertical forces at different velocity

The higher speed (9 km/h) had lower fuel consumption, as the tillage was made using the same engine speed (1800RPM), while both draft and vertical forces were significantly smaller, which create the hypothesis that the implement did not reach the optimum soil depth, which affects tillage quality.

For ensuring that the draft forces are smaller in different depths, another set of experiments were conducted at UK experiment (Latitude 52.46° Longitude 2.25). More specially, a Väderstad TopDown heavy multipurpose cultivator was used. The difference of this cultivator compared to the one used in the Greek experiments in which the working depth of the cultivator was set by the hydraulic system of the tractor, is that the soil depth can be secured using the embedded wheels of the machinery (**Figure 64**).

Figure 64: Väderstad TopDown heavy multipurpose cultivator

The UK experiments investigated the increase of fuel consumption and draft forces at different tillage depths (100mm and 250mm). **Figure 65** shows fuel consumption and draft forces on a shallow (south side) and a deep (north side) tillage plot at with a standard velocity of 7 km/h at the same engine speeds (1800 rpm).

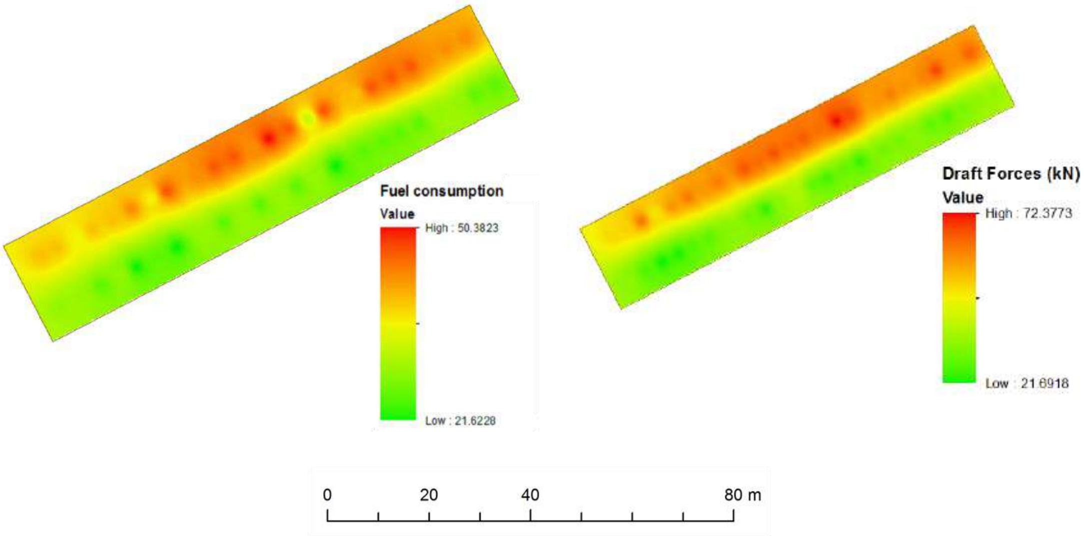


Figure 65: Fuel consumption and draft forces at different tillage depths

As presented in **Figure 65** an average 60% reduction of fuel consumption in shallow tillage (9.34 l/ha) compared to deep tillage (15.31 l/ha) was achieved working with a velocity of 7 km/h. Moreover, the draft forces, were closely related with the fuel consumption, as bigger torque was needed from the tractor engine in order to overcome the draft forces during tillage.

So the initial hypothesis that the forces are closely related on the tillage depth (see **Figure 63**), was confirmed. That was a logical result, as at higher speed it is expected to have higher forces due to higher accelerations to the soil part that cause a higher breaking of the clods. Obviously, the reduction of forces and fuels consumption have to be attributed to shallower working depth.

Moreover, the results of the Greek experiments (**Figure 63**) showed that the differences between the minimum and maximum values of the forces from the lower to the higher velocity were 12.1% for the draft forces and 21.81% for the vertical forces respectively. While both draft and vertical forces can be used to determine tillage depth reduction, vertical forces seemed to be more accurate on identifying the reduction, as they are the forces responsible for the depth of the tillage.

As for the effect of different tillage velocity and engine speed to the fuel consumption (l/ha), the results are presented in **Figure 66** and **Figure 67** for different operating settings of tractor velocity (5, 7 and 9km/h) and engine speed (1800 and 2200rpm). The different velocities at the same engine speeds were achieved by changing the gear of the tractor.

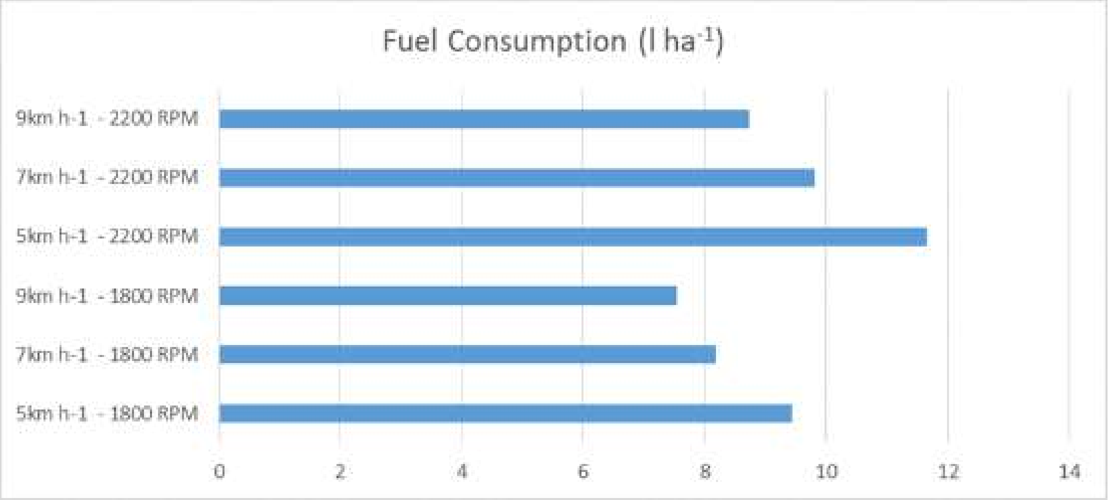


Figure 66: Fuel consumption at different tractor operation settings (chart)

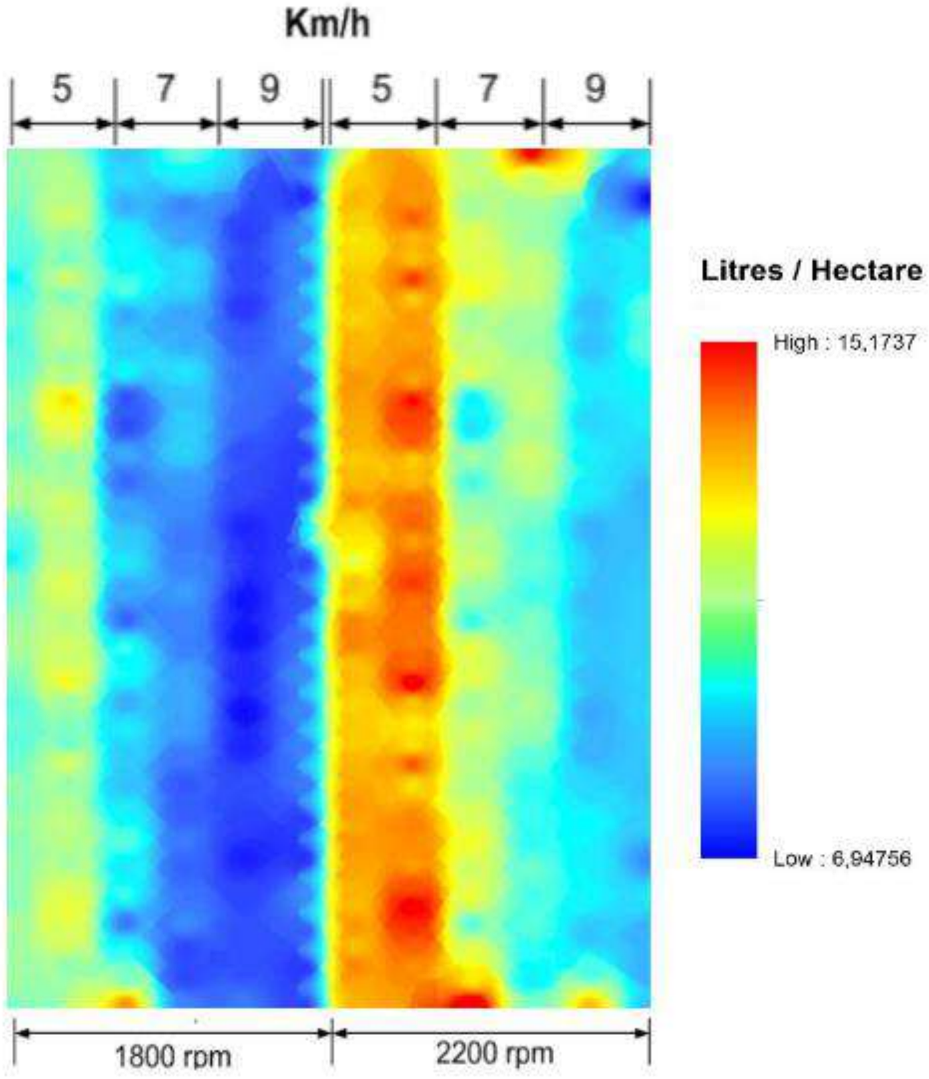


Figure 67: Fuel consumption at different tractor operation settings (spatial map)

The largest fuel consumption was achieved at the lowest velocity and the higher engine speed (11.65 l/ha at 5 km/h and 2,200 rpm), while the lowest fuel consumption was achieved with the highest velocity and the lowest engine speed (7.53 l/ha at 9 km/h and 1,800 rpm). The overall result is that reducing engine speed we have reduction of fuel consumption per unit of area. Although the higher speed (9 km/h) had lower fuel consumption, draft forces were significantly smaller (**Figure 68**), which indicates that the implement did not reach the set soil depth. **Figure 68** indicates also the variation of field conditions affecting the variation of draft forces but the overall result remains the same.

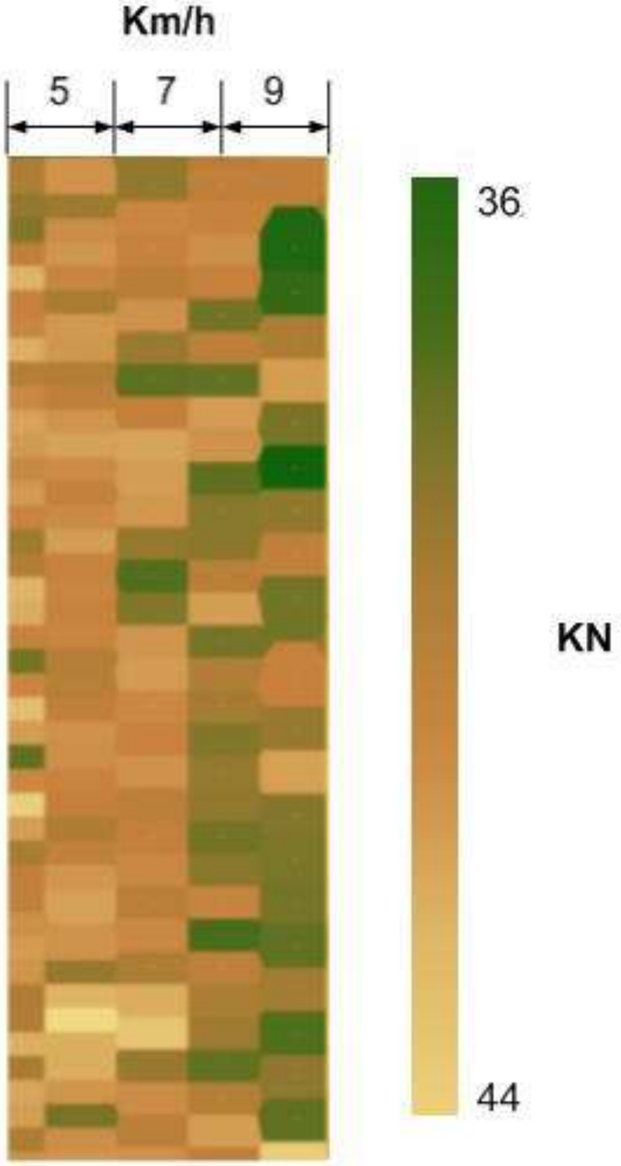


Figure 68: Traction map at different velocities

Figure 69 presents the fuel consumption measurements in l/h and l/ha for the aforementioned results. The fuel consumption in terms of l/h was increased with the increase of tractor velocity and engine speed. On the contrary, fuel consumption in terms of l/ha was reduced with the increase of tractor velocity and engine speed. The reduction of fuel consumption in l/ha, between 7 and 9 km/h was significantly lower compared to the reduction achieved between 5 and 7 km/h, as a result of the reduction of the traction forces at a working velocity of 9km/h.

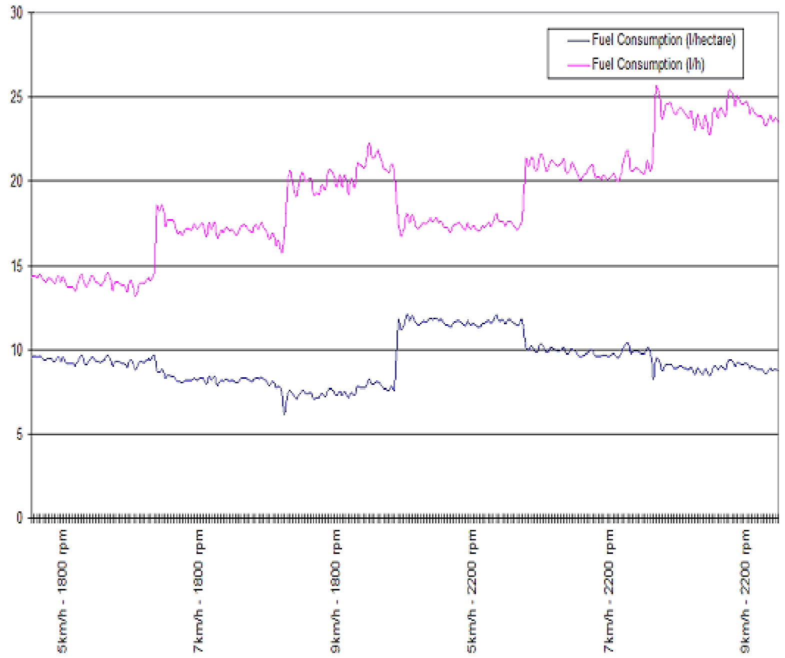


Figure 69: Fuel consumption at different velocity and engine speed

Aiming to robustly perform the comparison of fuel consumption at 7 km h^{-1} in the two different rpm levels of 1800 and 2200, and determine the statistical significance difference between the obtained measurements, an analysis of variance was performed by conducting a one-way ANOVA using Fisher's Least Significance Difference (LSD) test at 95% confidence level ($p<0.05$). STATGRAPHICS software was used for this purpose.

A total of 250 measurements were obtained and analyzed (measurement count). In Table 8, measurements are accompanied by the lower limit, upper limit, mean, standard deviation and standard error of each data set. The relatively low standard deviation and standard error observed values depict the homogeneity of the data sets, ensuring the reliability of the acquired measurements in each data set. Based on the results presented in Table 8, fuel consumption at 1800 rpm introduces a statistically significant difference compared to the corresponding fuel consumption at 2200 rpm.

Table 8: Comparison of fuel consumption (l/h) at 1800 and 2200 rpm with a velocity of 7 km h^{-1}. Different letters accompanying fuel consumption means indicate a significant difference between measurements, based on the Least Significance Difference (LSD) Fisher test ($p<0.05$).

RPM	Measurement count	Fuel consumption (l/h) Lower Limit	Fuel consumption (l/h) Upper Limit	Fuel consumption (l/h) Mean		Standard deviation	Standard error
1800	250	15.193	19.08	17.245	**a**	0.606	0.038
2200	250	18.746	22.779	20.558	**b**	0.648	0.041

Moreover, the differences between fuel consumption (l/ha) were evaluated at 1800 rpm. More precisely, measurements were obtained at 5 km/h and 7 km/h velocities. To determine the statistical significance difference between the obtained measurements, an analysis of variance was performed by conducting a one-way ANOVA using Fisher's Least Significance Difference (LSD) test at 95% confidence level ($p<0.05$). STATGRAPHICS software was used for this purpose.

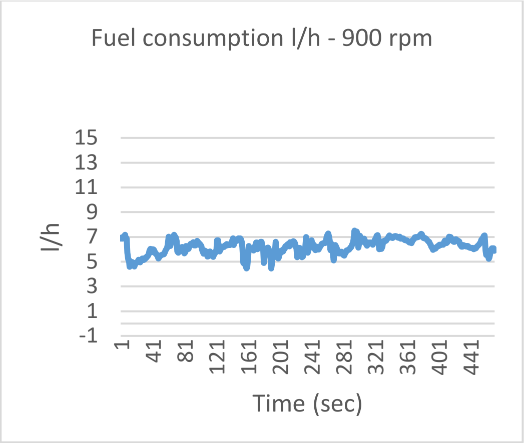
A total of 1198 measurements were obtained and analyzed (measurement count). At 5km/h the measurement count was 714 while at 7 km/h was 483 respectively. In Table 9, measurements are accompanied by the lower limit, upper limit, mean, standard deviation and standard error of each data set. The relatively low standard deviation and standard error observed values depict the homogeneity of the data sets, ensuring the reliability of the acquired measurements in each data set. Based on the results presented in Table 9, fuel consumption (l/ha) at 5 km/h introduces a statistically significant difference compared to the corresponding fuel consumption at 7 km/h, when velocity is stable at 1800 rpm.

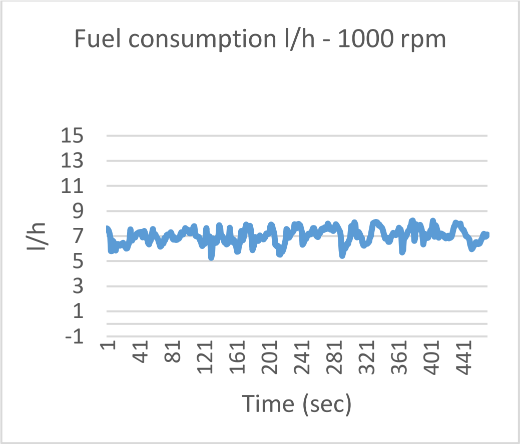
Table 9: Comparison of fuel consumption (l/ha) at 1800 rpm with differentiated velocity values of 5 and 7 km h^{-1}. Different letters accompanying fuel consumption means indicate a significant difference between measurements, based on the Least Significance Difference (LSD) Fisher test ($p<0.05$).

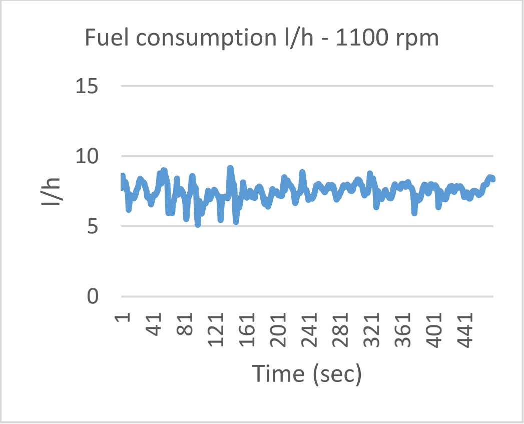
Velocity	Measurement count	Fuel consumption (l/ha) Lower Limit	Fuel consumption (l/ha) Upper Limit	Fuel consumption (l/ha) Mean		Standard deviation	Standard error
5 km/h	714	6.107	7.766	7.024	**b**	0.240	0.009
7 km/h	483	5.426	6.814	6.170	**a**	0.225	0.010

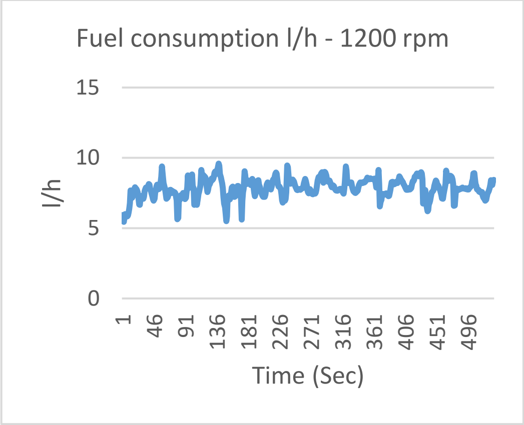
Taken into consideration that modern tractors can provide maximum torque over a very wide range of engine speeds by the use of electronic governor and Electronic Control Unit (ECU), a next set of experiments were conducted for analysing the fuel consumption reduction that can be achieved using a modern tractor.

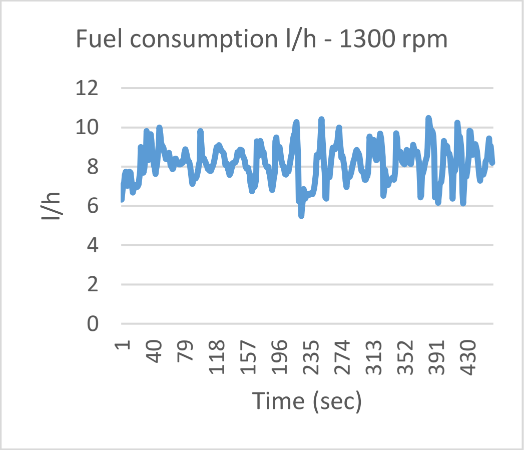
In these experiments the fuel consumption and the torque at engine speeds lower than 1800 rpm using Lamborgini R6.130 tractor were recorded and analyzed, tilling using a heavy rigid type cultivator at a velocity of 5km/h. The results are presented in the charts below.

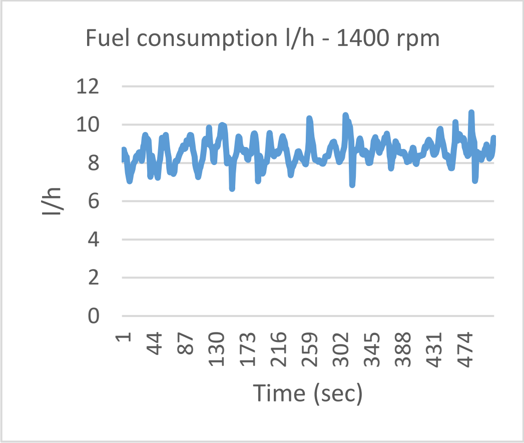

Fuel consumption l/h - 900 rpm

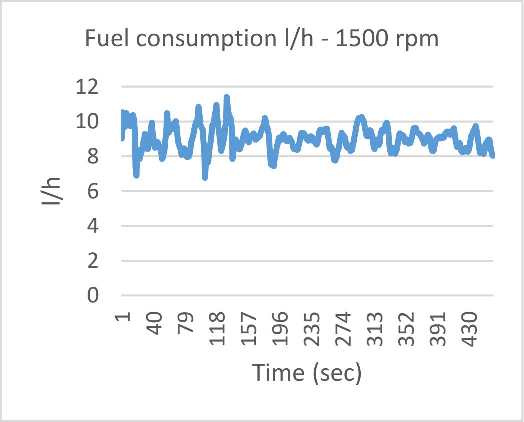

Fuel consumption l/h - 1000 rpm

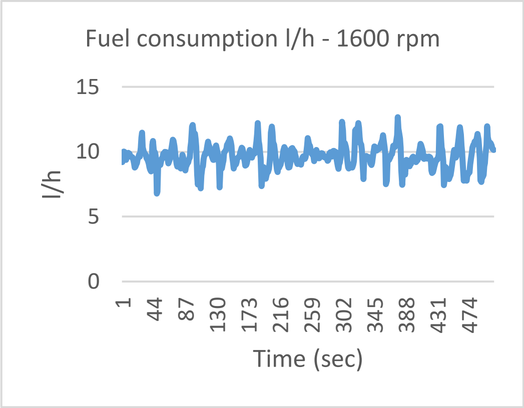

Fuel consumption l/h - 1100 rpm


Fuel consumption l/h - 1200 rpm


Fuel consumption l/h - 1300 rpm


Fuel consumption l/h - 1400 rpm


Fuel consumption l/h - 1500 rpm


Fuel consumption l/h - 1600 rpm

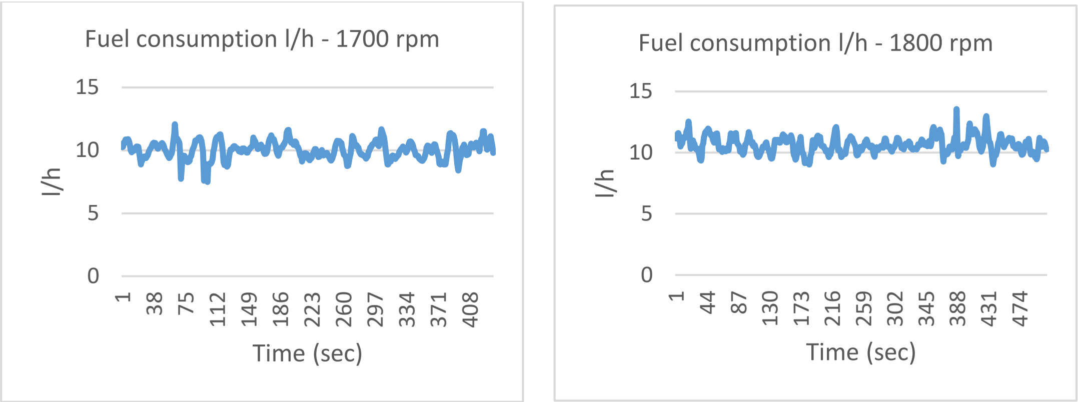


Figure 70: Fuel consumption at different engine speeds

The average consumption at each engine speed is presented at **Table 10**.

Table 10: Average fuel consumption in different engine speeds

Engine speed (rpm)	Average fuel consumption (l/h)
1800	10.65
1700	10.04
1600	9.67
1500	9.01
1400	8.57
1300	8.17
1200	7.84
1100	7.46
1000	7
900	6.2

As is evident from the table measurements, the engine speed (in revolutions per minute) correlates with the fuel consumption when the draft forces are the same. The correlation between consumptions is shown in the figure below (**Figure 71**).

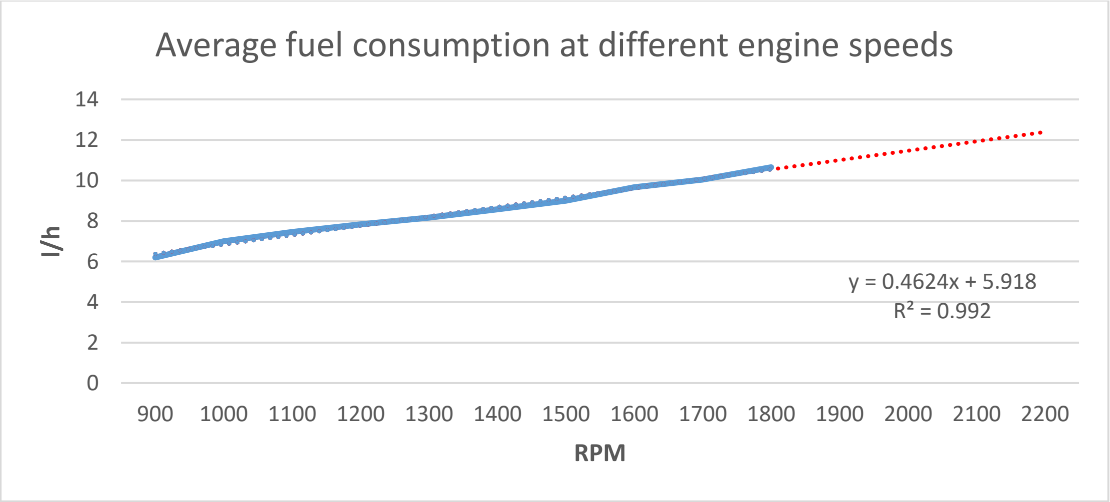


Figure 71: Average fuel consumption at different engine speeds

As can be seen from the chart above, at 2200 rpm which is the rated speed of most diesel engines in tractors, the fuel consumption is almost twice as much as at 900 rpm which is close to idle speed which most tractors have. Moreover, the fuel consumption follows a linear increase as the engine speed is increasing. The equation of the linear trendline of the aforementioned experiment was y = 0.4624x + 5.918 with a coefficient of determination equal to 0.992.

Respectively, the torque (%) of the engine at different engine speeds is presented in **Figure 72**.

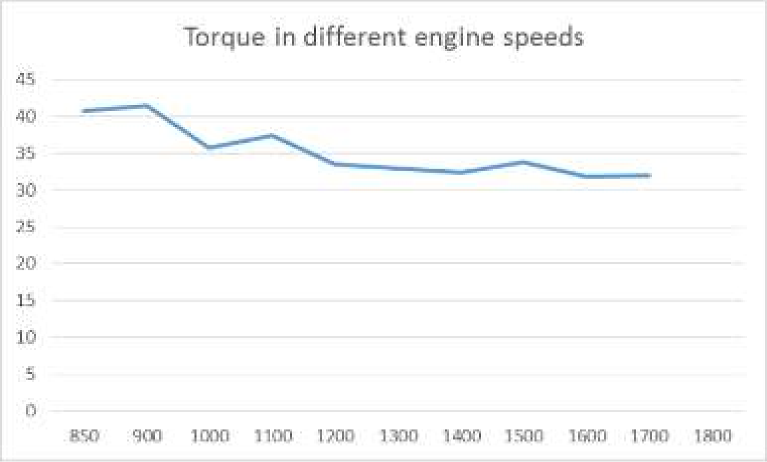


Figure 72: Average torque at different engine speeds

At the very low rpm (less than 1100) it seems that the tractor needs more torque for overcoming the traction forces, while for engine speeds bigger than 1200 rpm the torque follows a linear trendline. Till 1100 rpm, the engine was capable to handle the draft forces, but at 1000 rpm and below, incomplete combustion noticed at the tractor cabin. For this reason, we can assume that the optimal engine speed was at the point that the torque started to be linear (1200 rpm).

The results presented shows that working with a heavy duty cultivator, an increase in working velocity from 5-7 km/h led to approximately 15% decrease in fuel consumption from 9.43-8.19 l/ha at 1,800 rpm engine speed without affecting tillage depth. Driving at 5 km/h, an approximately 35% reduction in fuel consumption from 12.23-7.84 l/h was observed when engine speed was reduced from 2,200-1,200 rpm, which was the optimal engine speed for the instrumented tractor in Greek experiments.

The experiments proved in all occasions, that the optimal engine speed is always near the maximum torque provided by the tractor engine. So, a basic rule of thumb that can be applied from farmers using modern tractors, is that tilling in a speed engine 100RPM bigger than the RPM that the tractor has the maximum torque, can greatly reduce fuel consumption. The same rule can be applied to older tractors. The only difference is that most of the old tractors are not providing a big number of gears, minimizing the number of different configurations in terms of engine speed and velocity.

Overall, in these field experiments it proved that a significant reduction in fuel consumption can be achieved with the proper selection of working depth, tractor velocity and engine speed. Moreover, the usage of electronic equipment for measuring the parameters affecting fuel consumption and tillage quality can be used for real time optimization of the tillage operation by using a dedicated FMMIS.

As the only measurement retrieved from ECU is the fuel consumption, the solution can also applied in old tractors, by installing two flowmeters for measuring it. The system can work also efficiently without measuring the fuel consumption, by measuring only the forces, but in this case an uncertainty is been created regarding the real fuel consumption of the tractor.

The results of the experiments were used for developing an application for the tractor operators that can be used for reducing fuel consumption at tillage operations without affecting negatively the tillage quality.

The application designed for windows systems (notebooks, tablets) using C#. By running the application, the main screen is shown (**Figure 73**).

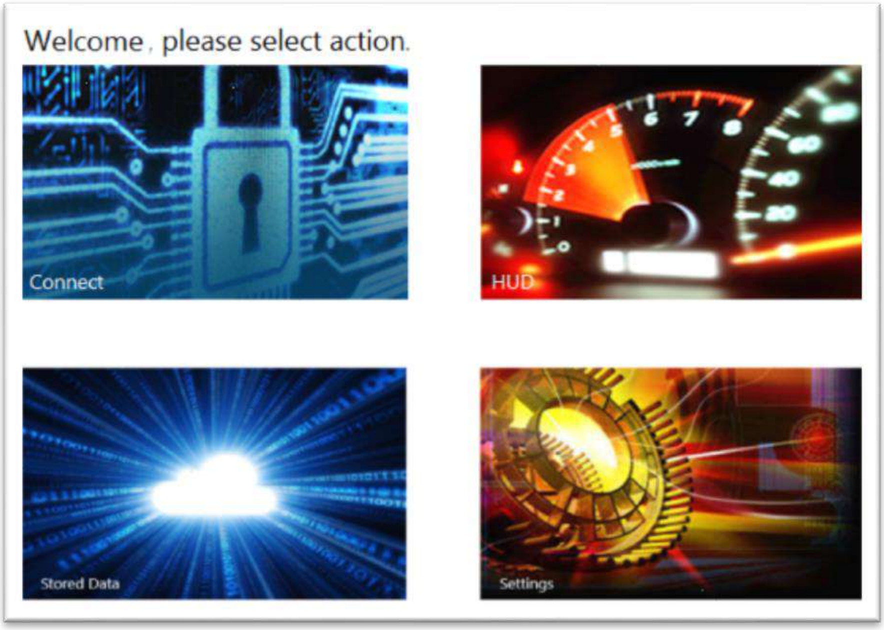

Welcome , please select action.

Figure 73: Main screen

The screen contains 4 different options. These are:

- Connect
- HUD
- Stored Data
- Settings

For making the system able to propose the optimal working parameters for minimizing fuel consumption, the 1st option ("**Connect**") must be clicked. By clicking the "Connect" title, the application starts to search the equipment connected (**Figure 74**).

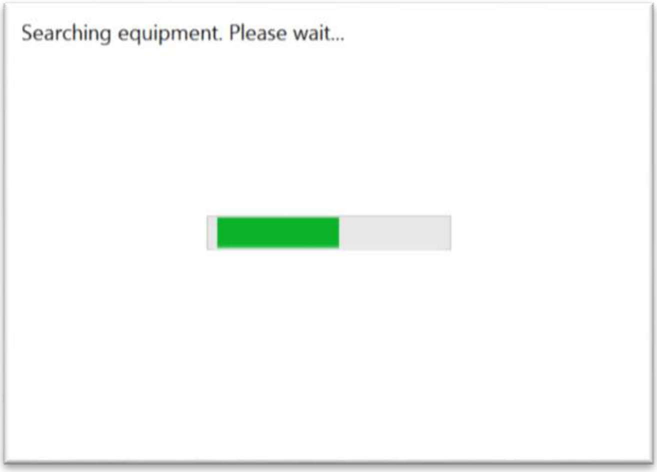

Searching equipment. Please wait...

Figure 74: Searching connected equipment

When all connected equipment is found, a screen mentioning that equipment appear (**Figure 75**). In total, the tool can recognize 3 different types of equipment. These are:

- **Tractors**: By reading the data for tractor Electronic Control Unit (ECU), the tool can recognize the tractor model.
- **Dynamometer**: the 2 different dynamometers which developed for the needs of this research are being supported. These are the three-point hitch dynamometer which can be connected to tractor's 3 point hitch and the simple dynamometer that can be connected to tractor's drawbar.
- **GPS**: The tool can use external GPS devices that are using NMEA0182 protocol

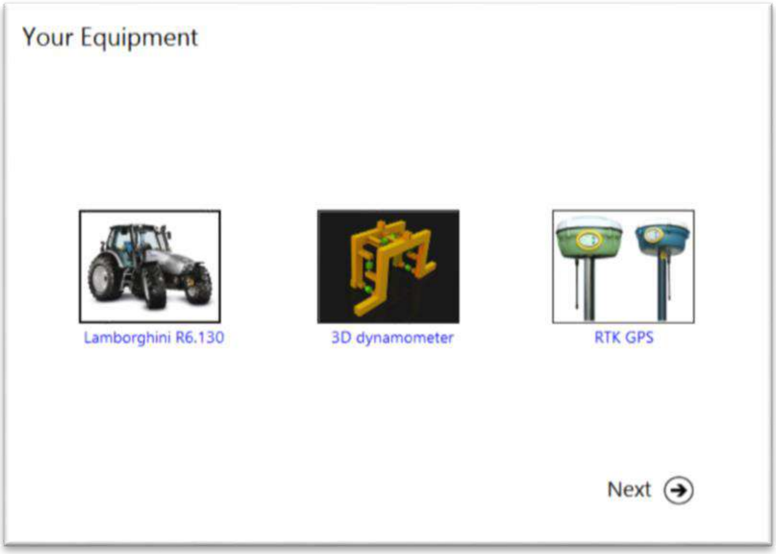


Figure 75: Connected equipment

After identifying the connected equipment, the tool asks from the tractor driver to select the type of the machinery that is attached to the dynamometer (**Figure 76**) and the machinery operational settings (working width and depth). **Figure 77** shows the machinery operational setting screen.

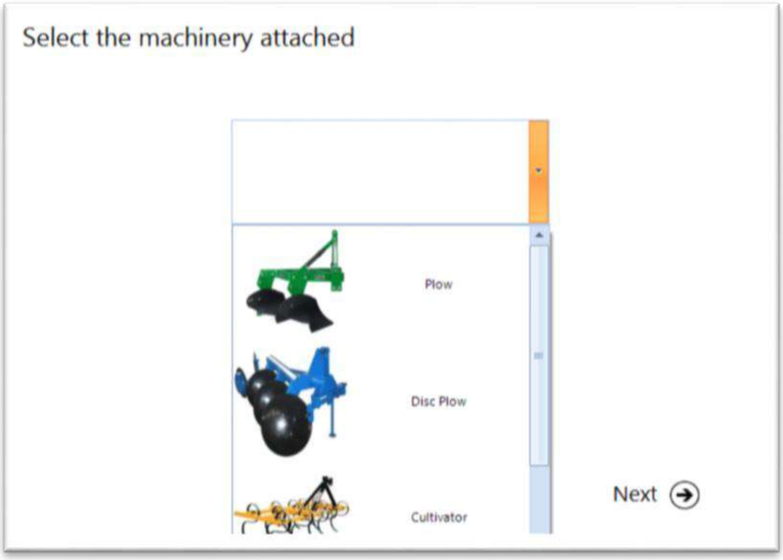
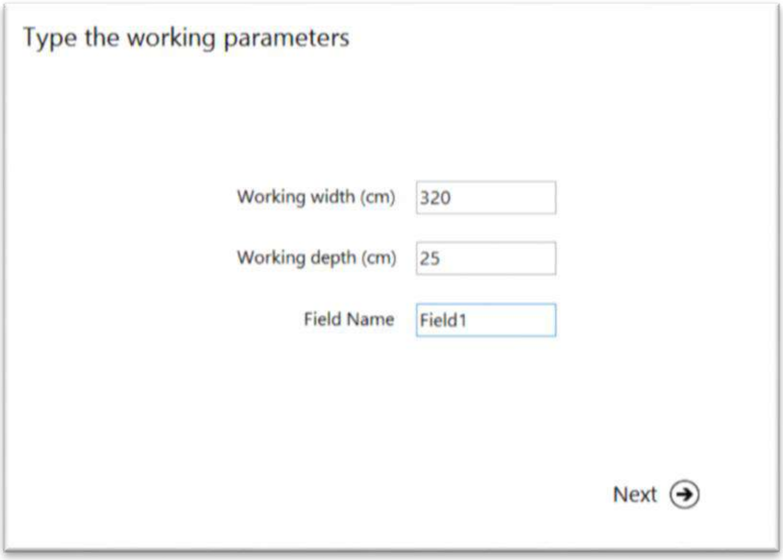


Figure 76: Selection of attached implement (agricultural machinery)



Type the working parameters

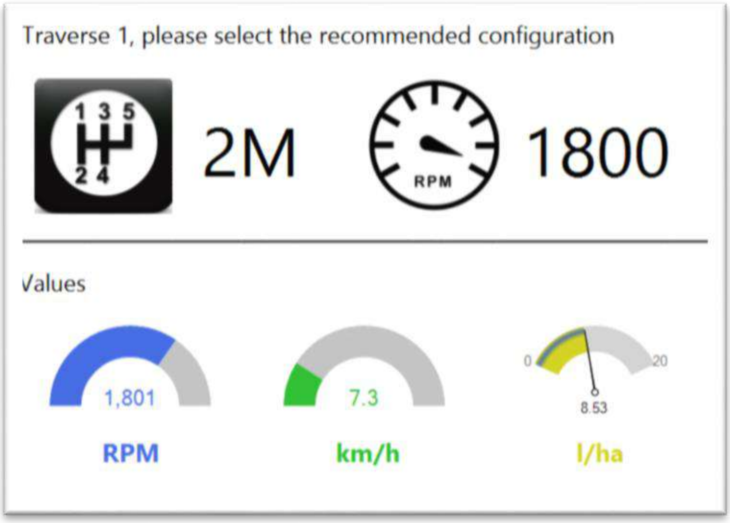
Working width (cm) 320

Working depth (cm) 25

Field Name Field1

Figure 77: Working parameters

After finding the connected equipment, the selection of the agricultural machinery attached and its working parameters, the system checks if the combination of these equipment and settings has been used before in the past. In case that they have used in the past, it suggests to the tractor driver (user) to make the first 3 traverses of the tillage operation with specific settings. In case that the combination (implement and settings) was not used before in the past, the system suggest the tractor settings for the first 6 traverses. During that suggestions, the screen (**Figure 78**) shows the suggested settings to the upper part of the screen, while the lower part of the screen shows the real time values (tractor velocity, engine rotational speed and fuel consumption) during that traverse.



Traverse 1, please select the recommended configuration

2M

1800

Values

1,801 RPM

7.3 km/h

8.53 l/ha

Figure 78: 1st traverse operational settings for finding the parameters for minimizing fuel consumption

In all traverses different configurations are recommended in terms of velocity and engine speed for evaluating the implement forces (for retaining tillage depth) and the fuel consumption (for minimizing consumption). In case that differences are recorded between the two load cells that are measuring the draft forces, or the two cells that are measuring the vertical forces a message appears to the tractor driver for adjusting the link or the level for obtaining optimal tillage (**Figure 79**). The same happens in case that the dynamometer will recorded side forces.

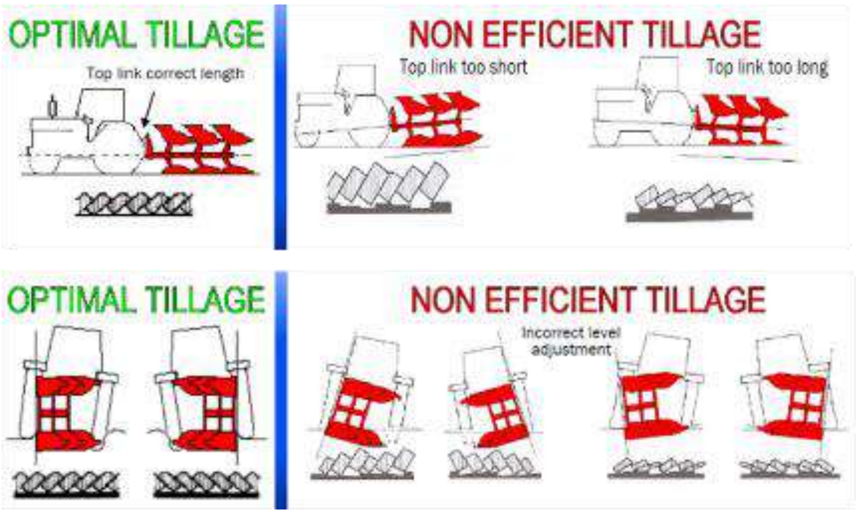
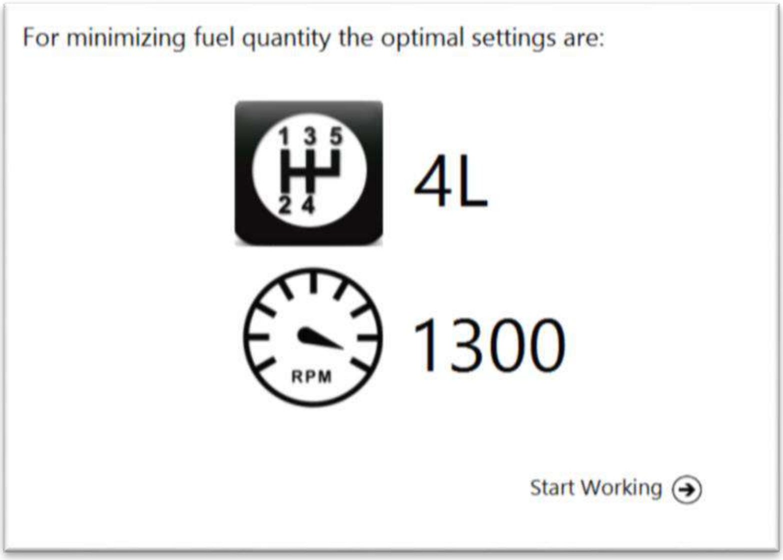


Figure 79: The tool proposes correction on link and level adjustment for optimizing tillage operation

From these suggestions and after the completion of the traverses needed, the system proposes the ideal tractor working parameters (**Figure 80**) for minimizing the fuel consumption during the tillage operation, and then a screen is appearing projecting in real time during the operation the fuel consumption, the tractor speed, the engine rotational speed and the forces (draft, vertical side) at the installed implement (**Figure 81**).


For minimizing fuel quantity the optimal settings are:

4L

1300

Figure 80: Optimal tractor operational settings for minimizing fuel consumption

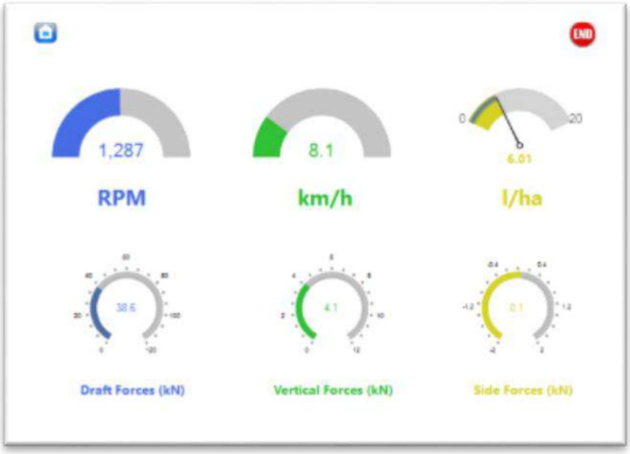


Figure 81: HUD (Head-Up Display) projecting values in real time

Data is stored locally, and if an active internet connection exists, then the tool sends the data in real time to the FMMIS web application though an API. Otherwise, and after the tillage operation completion, the user can upload the operation data to the web FMMIS when an internet connection will be found.

The final system architecture workflow for the optimization of tillage operations using the software tool for optimizing tillage operations and the FMMIS is shown in **Figure 82**.

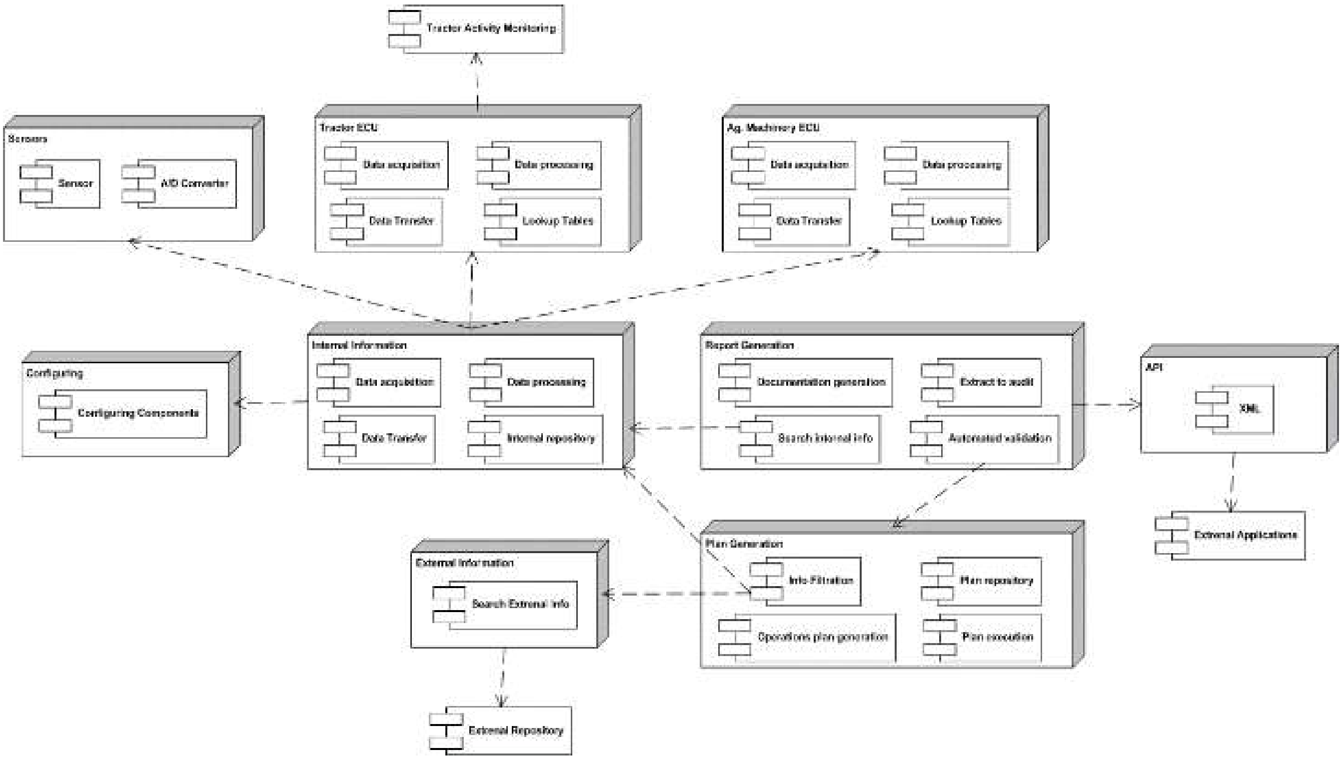


Figure 82: System architecture workflow for the optimization of tillage operations

3.2.4 Discussion and conclusions

Current technology in the agricultural machinery industry offers a very large number of tools and capabilities. The extended use of sensors, the Electronic Control Units (ECU) which is part of almost any new agricultural machinery and the use of communication protocols such as SAE J1939 protocol (which includes CANBus) and ISO 11783 (or ISOBUS), gives the ability to monitor and collect data on tractor and implement performance data which can benefit implement management decisions and lead to fuel savings. The developed system (dynamometers) was tested before the experiments with known weights and proved to be accurate and reliable for collecting real time machine performance parameters and is useful to analyze tillage operations in order to maintain soil tillage quality and reduce fuel consumption. Also the use of the SAE J1939 and NMEA protocols for tractor performance parameters and GPS position data respectively, and the ability to work with any load cell, gives the ability to the FMMIS to be used with various combinations of measurement systems, tractors, and GPS devices.

Case study results proved that torque, fuel consumption and draft forces are closely related, and demonstrated that analysis of tillage implement forces have great importance on fuel consumption and tillage depth. Both vertical and draft forces can reveal the tillage depth alteration, with vertical forces to project better that alteration. This was a result of the highest % of the difference between the maximum and the minimum values of the vertical forces (21.81%) compared to draft forces (12.1%) at the three different velocities that were tested (5-7-9 km/h).

Despite the vertical forces at the three-point hitch proved to give more accurate results compared to draft forces, even for implements which were installed at the tractor drawbar, the draft forces can reveal the tillage depth alteration. The ability of modern tractors with the use of electronic governor and ECU to render the maximum torque in a very wide range of engine speeds is an important factor for reducing fuel consumption. As is evident from the experiments, the engine speed (in revolutions per minute) correlates with the fuel consumption when the draft forces are the similar.

By increasing tractor velocity to the point that forces are not altered notably and by reducing the engine speed to its optimal value, a major reduction of fuel consumption can be achieved. Working with a heavy duty cultivator, an increase in working velocity from 5-7 km/h led to a 15% decrease in fuel consumption from 9.43-8.19 l/ha at 1,800 rpm engine speed without affecting tillage depth as measured by the vertical forces. Driving at 5 km/h, an approximately

35% reduction in fuel consumption from 12.23-7.84 l/h was observed when engine speed was reduced from 2,200-1,200 rpm, which was the optimal engine speed for the instrumented tractor in Greek experiments. A 60% reduction of fuel consumption in shallow tillage (9.34 l/ha) compared to deep tillage (15.31 l/ha) was achieved working with a velocity of 7 km/h. Overall, in UK experimental design, a significant reduction in fuel consumption was recorded with the proper selection of working depth, tractor velocity and engine speed.

The analysis of tillage implement forces (draft, vertical, side) are of great importance as they can indicate to the tractor driver the efficiency of the tillage operation (see **Figure 79**). Their analysis was achieved using the windows based software tool for spatial analysis of tractor-implement forces that was developed, and the system was able to alert, in real time, the tractor driver about the tillage depth alteration as well as for the correction on link and level adjustment for optimizing tillage operation.

Moreover, all the data can be viewed and analyzed from the FMMIS, providing a holistic experience to any interested stakeholder, from the farmer to researchers. For example, the spatial analysis of both draft and vertical forces as well as the spatial map of fuel consumption could be further linked with soil texture and organic matter to provide a more holistic system for spatial soil management.

Nowadays, the tractor industry has realized the importance of fuel consumption and its effects on farm sustainability. For improving the fuel consumption, a lot of different technological approaches have been applied. Most of them are related to the indication of the fuel consumption to the farmers[173] into tractor cabin or via telematics, or with the development of automatic gear boxes[174] able to change the gear ratio for minimizing engine speed (RPM) for the selected tractor velocity. In all of these approaches the importance of tractor velocity, the implement working width and the implement forces are not taken into consideration, while in the case of automatic gear boxes only the engine power required based on fuel flow is taken into consideration[28]. For these reasons, the fuel consumption provided to the tractor driver is not calculated in l/ha (which is the fuel consumption indicated the real cost of fuels in agriculture as l/100km is in automotive industry) but only in l/h. The FMMIS goes beyond the state-of-the-art by adding working width and the implement forces measurements into its methodology for providing the optimal tractor working parameters (velocity, engine speed) for achieving the maximum possible reduction of fuel consumption.

This research proposes a solution for optimizing the efficiency of tillage operations that disrupts the current market of agricultural industry by offering an innovative product able to reduce energy consumption and increase field efficiency of all tillage operations. Using the FMMIS, farming businesses can improve their competitiveness by better process control, reduced fuel consumption, and reduced implement maintenance. In addition, using the FMMIS go some way towards increasing the environmental sustainability of agriculture by reducing tractors' CO_2 emissions, lowering the amount of nitrous oxide (N_2O) released into the atmosphere from the agricultural domain, and increasing energy sustainability. Finally, compatibility even with older agricultural equipment (using flow meters for measuring fuel consumption) can bridge the gap between large scale farms with "high tech" agricultural equipment and small scale farms with "low tech" equipment by being applicable to both the "high tech" ISOBUS equipment and the "low tech" mechanically controlled tractors.

3.3 Development of an Unmanned Ground Vehicle (UGV) for agricultural operations at orchards and vineyards

3.3.1 Introduction

The next revolution in agriculture and food will be based on new technologies and robotics. This fact was highlighted as a key theme in the foresight report in digital technology for H2020 strategic programming (Foresight Services to support strategic programming within Horizon 2020 Foresight report (D3) KK-06-14-077-EN-N)[175].

Autonomous vehicles have long been used in strictly controlled predictable environments in industrial production and warehouses. Creation of autonomous vehicles in agriculture where the natural environment is only semi-structured and less predictable has been more of a challenge. Serious research began in the early 1960's, mainly into automatically-steered tractors, a review of which may be found in Wilson (2000)[176]. Advances in mechanical design capabilities, sensing technologies, electronics, and algorithms for planning and control have led to a possibility of realizing field operations based on autonomous robotic platforms (Bak et al., 2004)[177]. Nowadays, the use of ICT and autonomous vehicle technologies is rapidly evolving. Farmers are increasing the use of advanced technologies for completing agricultural tasks and for managing their farms. Nowadays, there are a lot of commercial Unmanned Aerial Vehicles solutions available at the market, but this is not still happening for the case of UGV's as most of them are prototypes, or very small in size and capabilities.

One of the most important issues in agricultural robotics is automatic guidance of driverless tractors as most of the tasks undertaken are point to point field navigation. An early study has been carried out by Widden and Blair (1972)[178] who propose a method for guiding a driverless tractor using a cord buried a few inches below the surface of the ground for its guidance marker. Later the potential for combining computers with image sensors provided opportunities for machine vision-based guidance systems. Chateau et al. (2000)[179] developed a guidance system for agricultural vehicles using a laser rangefinder while Subramanian et al. (2006)[180] proposed machine vision and laser radar based autonomous vehicle guidance systems for citrus grove navigation. A machine vision-based method for robust recognition of crop rows was presented by Jiang et al. (2010)[181] and Xue et al. (2012)[182] introduced a variable field of view (FOV) machine vision based guidance system to navigate a robot through cornrows.

All recent applications for autonomous driverless vehicles have been carried out using Global Positioning System (GPS) for agricultural vehicle navigation. Bevly (2000)[183] used the GPS measurements on a tractor towed implement for position control of the implement through automatic steering of a farm tractor performing various agricultural tasks. Billingsley (2000)[184] argues that the combination of both techniques, that is, machine vision and GPS guidance is the solution to an autonomous farming mobile vehicle of true commercial value.

Mobile internet is a fast growing technology, and the adoption of mobile internet as new Information and Communication Technology (ICT) in everyday life is huge. The 4G and 5G standards which are used nowadays, makes possible the access to fast internet connection everywhere. This can help on remote controlling and operation of UGVs, as well as for retrieving their performance data in real time. The first attempts for operating and controlling vehicles from distance have started in the early 1900’s, but systems of vehicle teleoperation started to be used widely in the 1970’s (Fong et al., 2001)[185]. The first tries for controlling robots via the World Wide Web, have started at in the middle of 1990’s when the WWW started to expand all over the world. Nowadays, there are commercial robots that can be controlled from web – based applications.

Fountas et al. (2010)[186] established a methodology for decomposing the agricultural operations into robotic behaviors and Blackmore et al. (2008)[187] set the specification requirements for agricultural robots, which should behave sensibly in a semi-natural environment, over long periods of time, unattended, whilst carrying out a useful task.

Aim of the following thesis research task was to develop an agricultural UGV, and to connect it into the FMMIS, for analysing its operation data and controlling it. For achieving this task, along all the other implementations, a middleware software was develop for creating truly autonomous agricultural vehicles to fulfil all the required agronomic functions of plant-scale precision farming operations, and thus realize all the cultural practices of various crop systems.

3.3.2 Materials and Methods

3.3.2.1 Unmanned Ground Vehicle

"Dionysus" (**Figure 83**) is an UGV that has been created to be able to complete various agricultural operations into grapevines and orchards. It has two-wheel drive and two-wheel steering, and it uses gasoline engine as a power source.

Figure 83: Dionysus robot

As a lot of agricultural UGV's that were created from research projects and activities, are experiencing problems on efficiently moving throughout the fields, it was decided the UGV to be developed based on an existing platform that has the capability to move inside the agricultural harsh environment without any problem. For this reason, the base platform selected for developing the robot was the KYMCO Maxxer 90 ATV (**Figure 84**). Its selection gave to the robot all the necessary power and torque needed for moving inside the fields, and made its implementation cheaper compared to designing and constructing a new robot base platform and its components (e.g. engine, transmission system etc.) from the scratch.

Figure 84: KYMCO Maxxer 90 ATV

Maxxer 90 has a 90cc petrol engine coupled with a centrifugal CVT transmission which allows for forward speed control via the throttle cable and cable operated brakes on both front and rear. The compact design of the ATV is ideally suited for operations within fields. The forward speed of the platform has been reduced by changing the original sprockets and by adding to more additional sprockets at the transmission system (**Figure 85**).

Figure 85: Modified Transmission system

Drive control of the platform is performed by both the throttle system (acceleration and engine braking) and the brakes system (deceleration). Velocity feedback is taken by an inductive sensor system. Input to the Drive system can be from either the dash board switches (**Figure 86**), RC controller (**Figure 87**) or from the PC ECU (laptop) via serial input depending on the selected operation mode. The drive ECU board processes the inputs, feedback and outputs and is based around the 20M2 PICAXE pic microcontroller chip (**Figure 88**).

Figure 86: Dashboard switches

Figure 87: RC controller

Figure 88: 20M2 PICAXE pic microcontroller chip

The throttle cable is operated by a liner actuator via a lever system. The actuator sourced from LINAK (**Figure 89**) it has a stroke of 70mm with a max force of 200N and provides position feedback via an internal potentiometer.

Figure 89: LINAK actuator used for throttle control

The actuator is controlled via a high amp (20A) H bridge module. This module is integrated on the Drive ECU board (**Figure 90**) which also receives the potentiometer feedback and was developed around a 20M2 PICAXE pic microcontroller chip.

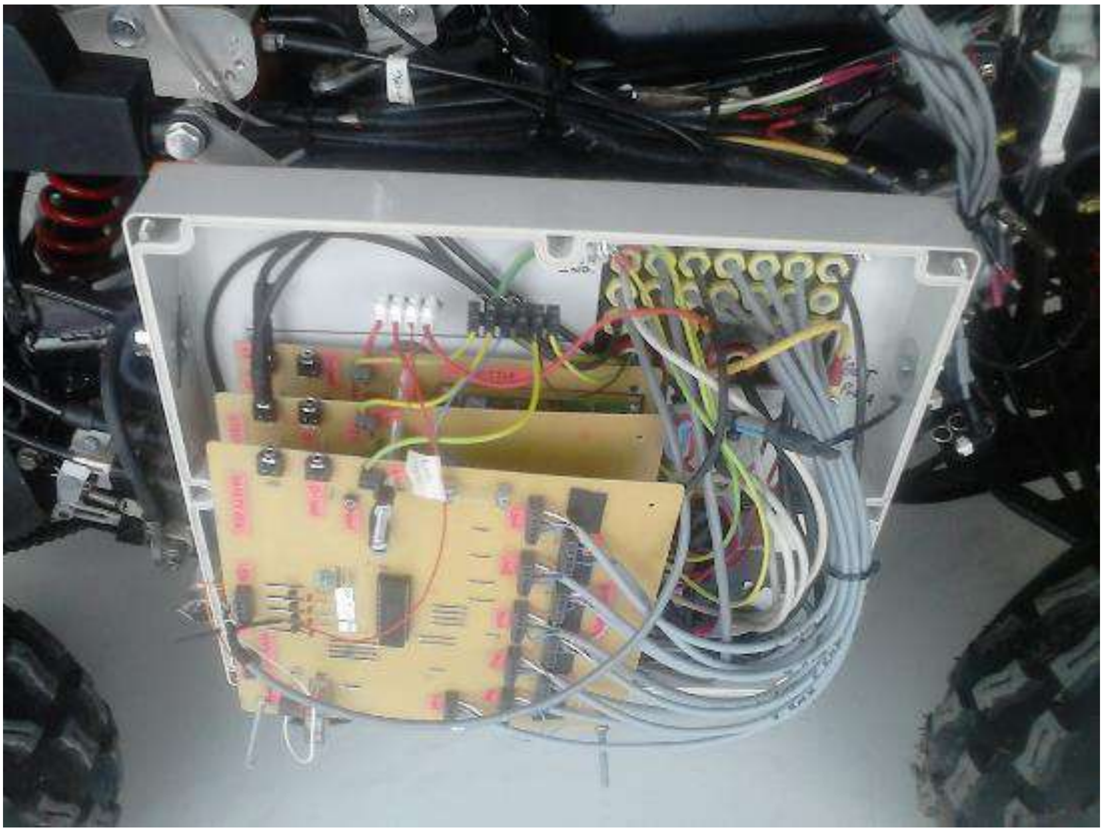


Figure 90: Dionysus ECU boards

The brake is operated by a linear actuator via a lever system. The actuator is from LINAK, it has a stroke of 40mm with a max force of 300N and provides position feedback via an internal potentiometer. The actuator is once again controlled via a high amp (20A) H bridge module. The drive nodule is again integrated on the Drive ECU board which also receives the potentiometer feedback and was developed around a 20M2 PICAXE pic microcontroller chip.

Vehicle speed feedback is taken from an inductive sensor which is triggered high / low (on / off) by the teeth on the revolving rear sprocket which pass its tip. These high / low pulses are input to the drive system controller where the count command can be used to record the number of teeth which pass the sensor in a set period. The inductive sensor user was a Pepperl & Fuchs with a sensing range of 1.5mm (**Figure 91**).

Figure 91: Pepperl & Fuchs inductive sensor

With the platforms wheel gear and rear sprocket setup the number of teeth which pass the sensor in 0.1 seconds is directly related to the forward vehicle speed in kilometers per hour (1 tooth in 100ms = 1km/h).

The platforms steering is operated by a liner actuator via a lever system fitted to top of the steering column in place of vehicles original handle bars. The actuator is LINAK (**Figure 92**) and it has a stroke of 100mm with a max force of 1700N and provides position feedback via an internal potentiometer.

Figure 92: LINAK actuator used for steering

The actuator is once again controlled via a high amp (20A) H bridge drive module. This drive module is integrated on the Steering ECU board which also receives the potentiometer feedback and was developed around a 20M2 PICAXE pic microcontroller chip. Input to steering system can be either the dash board switches, RC controller or from the PC ECU via serial input depending on the selected operation mode.

The ultrasonic system creates an invisible safety zone surrounding the vehicle. Anything that enters the zone is firstly warned be a flashing beacon. If the object becomes closer to the vehicle a warning signal will then be fed to the drive system causing a safety action to be taken. The system is based around digital sensors by Pepperl & Fuchs (**Figure 93**) which give two digital outputs which are programmed to two trigger points within their 4 meter range.

Figure 93: Ultrasonic sensors

These two trigger points give the warning and the action point for the systems reactions they can be reprogrammed at any time using Pepperl & Fuchs software. A total of 10 ultrasonic sensors (**Figure 94**) are used to complete the full 360 degree safety zone. These sensors are synchronized together to avoid interference between adjacent sensors. The sensors are integrated through the safety ECU board which applies a PICAXE 40X2 microcontroller. The microcontroller processes the inputs from each sensor and calculates what action to take, either activating warning lights or sending the action signal to drive ECU.

Figure 94: Ultrasonic system with 10 sensors

The hardwired failsafe system involves various safety devices linked into the platforms original engine kill safety system it therefore stalls the engine instantly if a device is activated. The devices linked into the system are:

- 4 Red stop buttons (**Figure 95**)
- A radio transmitting "dead's man handle" (**Figure 96**)
- Safety bumper (**Figure 97**)

Figure 95: Red stop button

Figure 96: Radio transmitting "dead's man handle"

Figure 97: Safety bumper

The system requires current through the series circuit whilst operating therefore, the buttons and the bumper switches are normally closed to break the circuit when activated. The dead's man handle is however; normally open so that it must permanently be pressed for the circuit to be complete and for the engine to run.

The metal assemblies on the platform have been designed to incorporate multiple functions. These functions include mounting of permanent hardware such as actuators and battery, mounting of operation sensors including the SICK laser and RTK GNNS and also with overall vehicle aesthetics in mind. Key to the assembly design was to pick up on mounting points available on the base vehicle to avoid any adaption to it.

3.3.2.2 Unmanned Ground Vehicle Operation modes

When **neutral mode** is selected on the platforms dash board the drive and steering ECUs are programmed to look for changes in logic (high / low voltage) coming from the dash board switches. The program then indicates actions based on these logic levels of the various switches and buttons sending signals to the various actuators drive H bridges. For example when the steer left switch is pressed the logic to the microprocessor is turned from high to low. Then the microprocessor sends the signal to the steering H-bridge to power the actuator closed turning the steering column and the wheels to the left.

When **RC mode** is selected the drive and steering ECUs are programmed to start looking for PWM signals input from the RC receiver. These variables signals are read using the pulsin command and can then be used to trigger various actions. By comparing the signal to the position feedback from actuators or speed feedback from the inductive sensor fully proportional control can be activated.

When the **autonomous mode** is selected the drive and steering ECUs start to look for serial input signals coming in from the system ECU (laptop). These signals are messages sent from the middleware containing information on the required state of the vehicle. The requirements sent are forward speed and steering angle which the ECUs then use along with the feedback systems to calculate relevant actions to take.

3.3.2.3 Software for operating UGV's and transfer data to FMMIS (middleware)

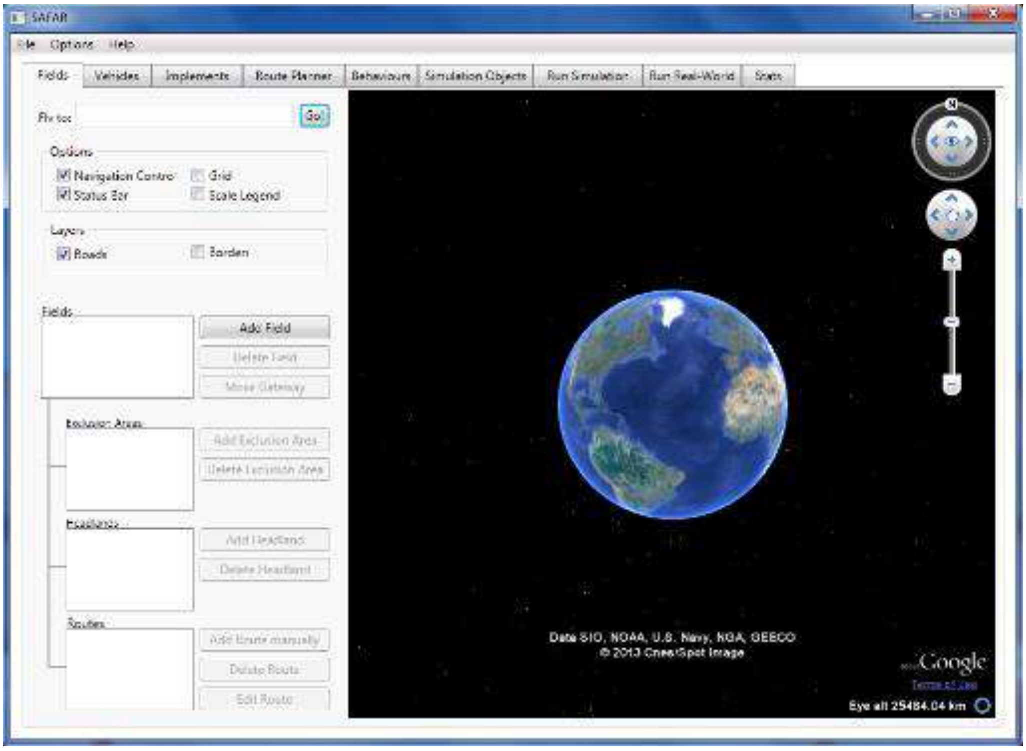
The designed software includes a windows desktop application that integrates the use of Google Earth^{TM} taking advantage of its services zooming in every area around the global. It also employs Microsoft Robotics Developer Studio (MRDS) due to its high degree of similarity and the congruence of its operation with that desired for the architecture to be built using it. This includes concurrency and a distributed object-oriented approach.

The developed object-oriented design considers robotic architectures to refer primarily software architectures, rather than hardware. Thus the architecture utilized can remain device-independent while giving scope for arbitrary agricultural robot hardware designs to be accommodated within the control system. Since an object-oriented design approach has been taken under consideration, the physical hardware can also match the logical design to support all kind of behavioral modes.

The main entity in the software is the Farm. Its users can open and save .farm files containing all the data of the farms created. A farm must have at least one field. Except fields the user can import vehicles and implements with different configurations and design routes that the vehicles will follow. Finally the software is able using MRDS, to simulate the procedure of route following in a virtual world and also control the robot in real-world environment.

In order to be implemented to the middleware, several agricultural robot models have been built to work in the Visual Simulation Environment of MRDS, along with object-types appropriate for outdoor agricultural robotics (such as gateways, rocks, posts, field boundaries and excluded areas due to roads, ditches and other obstructions or hazards).

The purpose of the middleware (**Figure 98**) was to develop a set of designs, tools and resources to help promote the development of agricultural robots.



☑ Navigation Control
☐ Grid
☑ Status Bar
☐ Scale Legend
☑ Roads
☐ Borders

Figure 98: Middleware GUI

At the top of the screen (**Figure 98**), nine tabs can be distinguished:

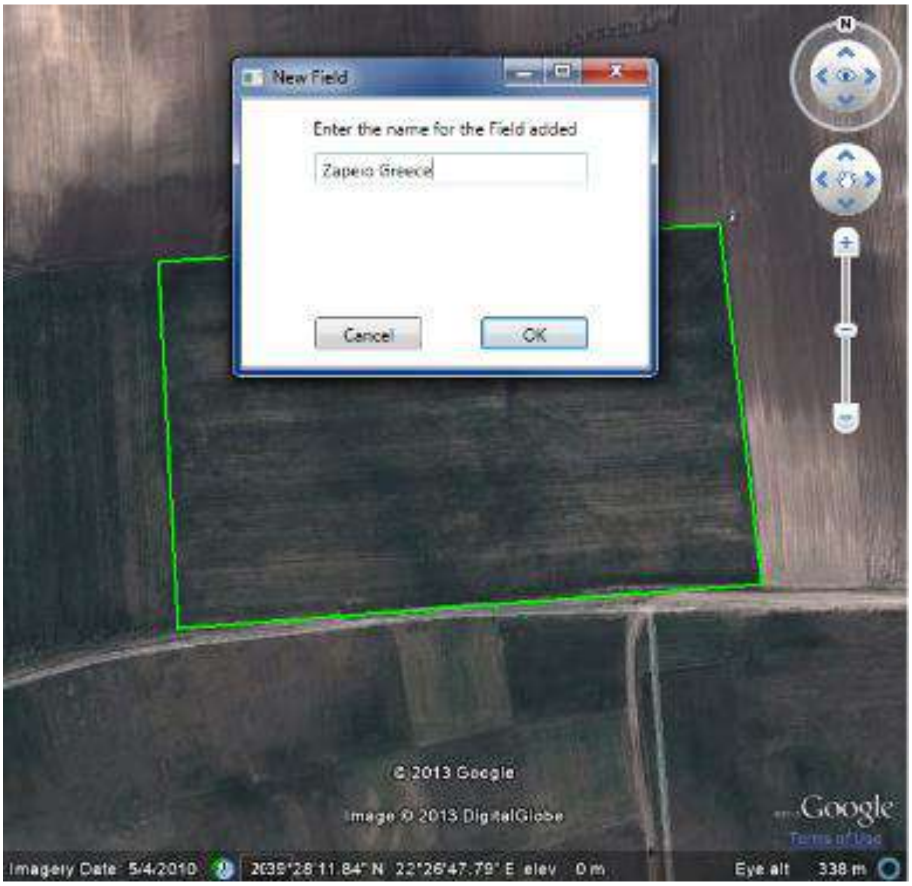
- Fields
- Vehicles
- Implements
- Route Planner
- Behaviours
- Simulation Objects
- Run Simulation
- Run Real-World and
- Stats

The functionality of each tab is described in the following sections. Using the "**fly to**" search box the desired place can be located e.g. "Zapeio", or entering the latitude and longitude values, e.g. "39.2816, 22.2643″ and pressing the button "Go" the user is redirected to the chosen area.

In addition, the following parameters of Google Earth plugin are available:

- Navigation Control
- Status Bar
- Grid
- Scale Legend
- Roads
- Borders

In the **Fields tab** the user can add a field by pressing “**Add Field**” button and then to add points with the mouse to define the field boundary with a polygon. When the user presses mouse’s right button the software calculates the borders of the selected area and creates the field asking first for a name (**Figure 99**).



Enter the name for the Field added

Zapeio Greece

Figure 99: Adding Field

When the user creates a new field, the gateway (the entry point of the UGV into the field) is automatically placed in the first point of the boundary. By pressing the “**Move Gateway**” button its position can be changed. Picking the gateway with the mouse the user can drag it to the desired position. In the created field, exclusion areas and headlands can be added by pushing the appropriate button and doing the same procedure as adding a field.

Furthermore, the user can add routes to the selected field that will be used later by the **Route Following service** either in simulation or with real vehicles. Pressing the "**Add Route manually**" button the user can start adding the waypoints that will describe the route. Each waypoint has properties that can be modified later by pressing the "**Edit Route**" button. These properties are:

- The **waypoint** number.
- **Northing**, in UTM coordinates.
- **Easting**, in UTM coordinates.
- **Tolerance**, in meters. It is the distance from the specific waypoint at which it will be considered reached.
- **Speed**, at which the robot should move until it reaches the waypoint.
- **Navigation Mode**. Possible values are '**STWP**' (Straight to Waypoint) and '**MXTE**' (Minimize Cross Track Error). The navigation algorithm is explained below
- **Task**. For now, the possible values are "**Lift Cutters**" and "**Lower Cutters**". They can be empty too.

When drawing a route, waypoints can be added with "Lower Cutters" Task and "MXTE" Navigation Mode by holding the SHIFT key down when clicking. Otherwise, the waypoints are added with "Lift Cutters" Task and "STWP" Navigation Mode.

Figure 100 illustrates the Vehicles tab where the user can import new vehicles to the farm.

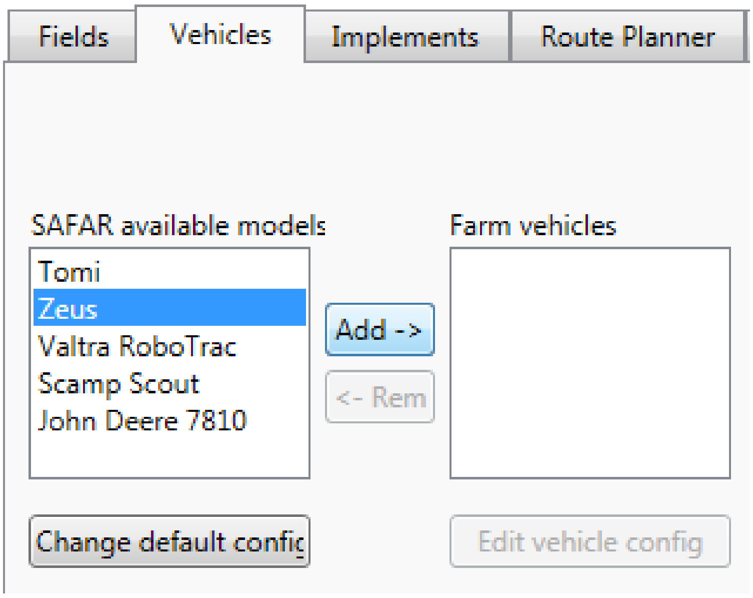
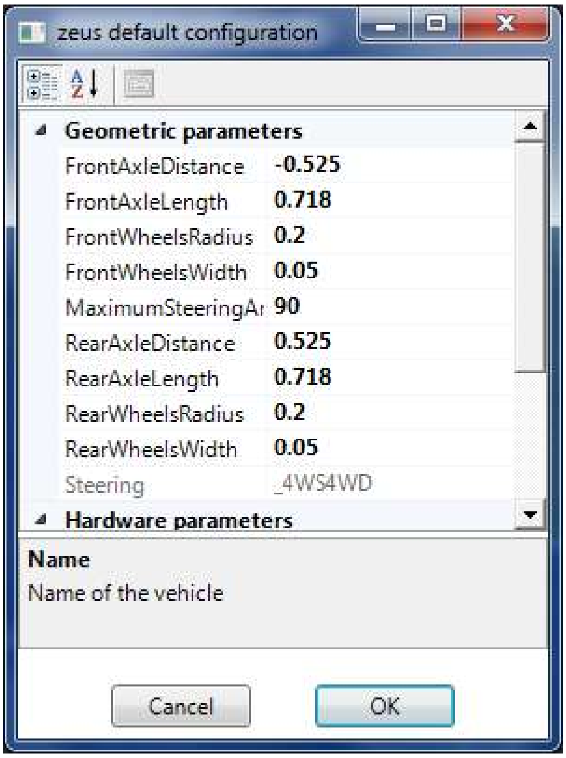


Figure 100: Vehicles tab

By selecting the desired vehicle from the list at the right and by pressing “**Change default config**” button its default values can be modified with the help of a dialog window (**Figure 101**).



Geometric parameters

FrontAxleDistance	-0.525
FrontAxleLength	0.718
FrontWheelsRadius	0.2
FrontWheelsWidth	0.05
MaximumSteeringAı	90
RearAxleDistance	0.525
RearAxleLength	0.718
RearWheelsRadius	0.2
RearWheelsWidth	0.05
Steering	_4WS4WD

Hardware parameters

Name
Name of the vehicle

Figure 101: Vehicle’s default configuration

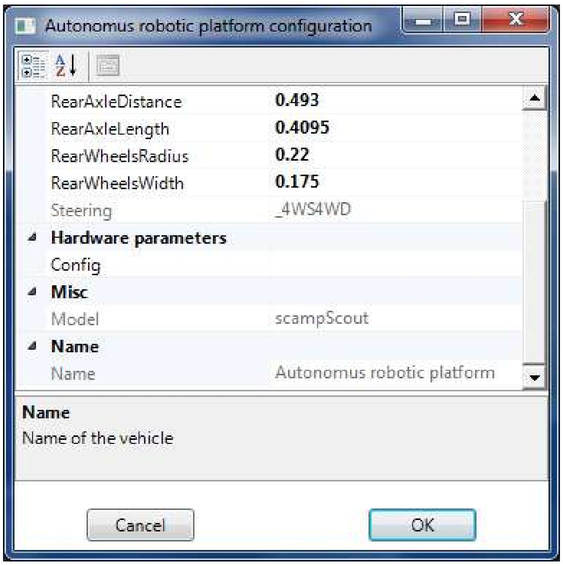
By pushing the “**Add->”** button the new vehicle is added to the farm while the software prompts for its name (**Figure 102**).

Enter the name for the new Scamp Scout vehicle

Autonomus robotic platform

Figure 102: Dialog for entering vehicle’s name

By selecting the desired imported vehicle and by pressing “**Edit vehicle config**”, vehicle’s specific values can be configured (**Figure 103**).

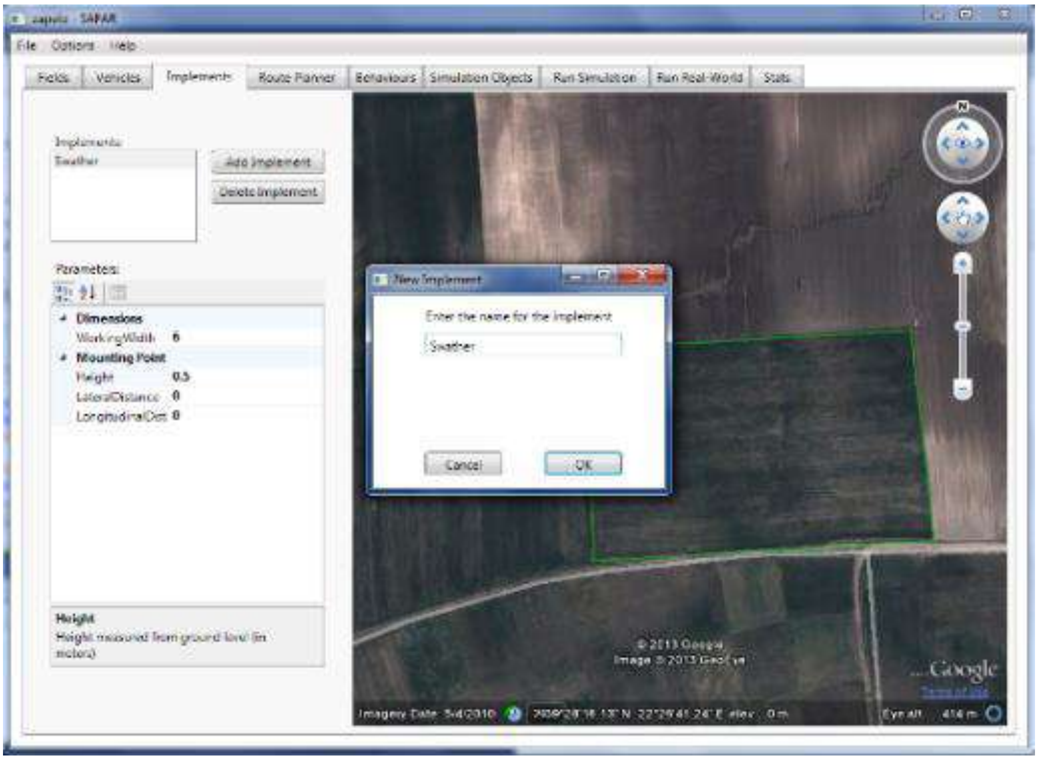


RearAxleDistance 0.493
RearAxleLength 0.4095
RearWheelsRadius 0.22
RearWheelsWidth 0.175
Steering _4WS4WD
Hardware parameters
Config
Misc
Model scampScout
Name
Name Autonomus robotic platform

Name
Name of the vehicle

Figure 103: Vehicle configuration dialog

In the **implements tab** the user can add implements to the configured farm. By pressing the ”**Add Implement**” button the software prompts for a name as seen in **Figure 104**.



Implements:
Swather

Parameters:
Dimensions
WorkingWidth 6
Mounting Point
Height 0.5
LateralDistance 0
LongitudinalDist 0

Height
Height measured from ground level (in meters)

Enter the name for the implement
Swather

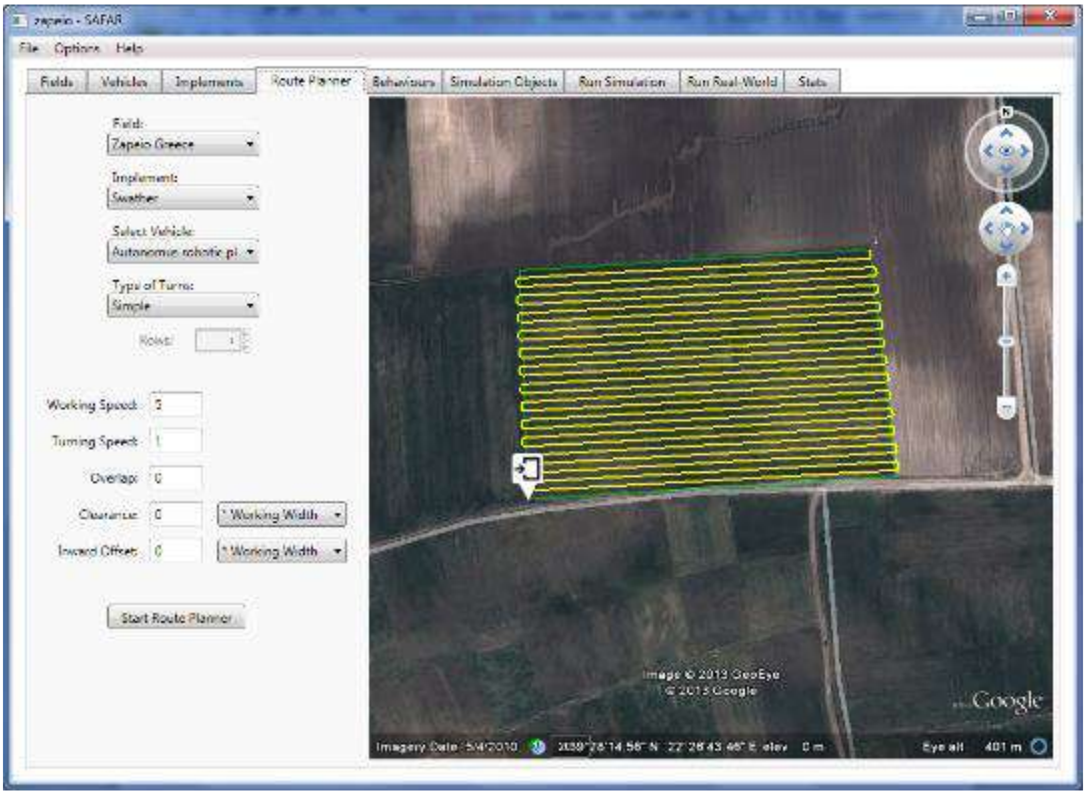
Figure 104: Implements tab

As soon as the implement has been created its following properties can be configured:

- Working width

- Height
- Lateral distance
- Longitudinal distance

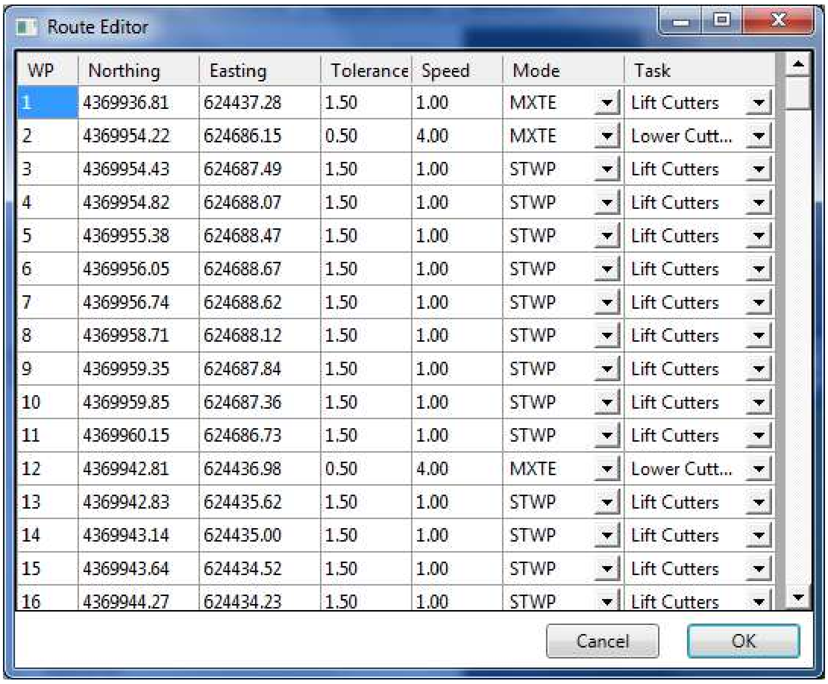
In the **Route Planner tab** (**Figure 105**) the calculated routes of the specific field can be created and be illustrated. For the route to be calculated the user has to choose the desired field, vehicle and implement from those which have been created and also the type of turning from the following four options: **Simple**, **LightBulb**, **FishTail** and **SkipRows**. By choosing the last one, the number of the skipped rows must also be selected. In addition, the **working speed**, **turning speed**, **overlap**, **clearance** and **inward offset** must also be filled in by the user. The last two can be in meters or multiplied by working width.



Field: Zapeio Greece
Implement: Swather
Select Vehicle: Autonomic robotic pl
Type of Turns: Simple
Rows: 1
Working Speed: 3
Turning Speed: 1
Overlap: 0
Clearance: 0 * Working Width
Inward Offset: 0 * Working Width

Figure 105: Route planner tab

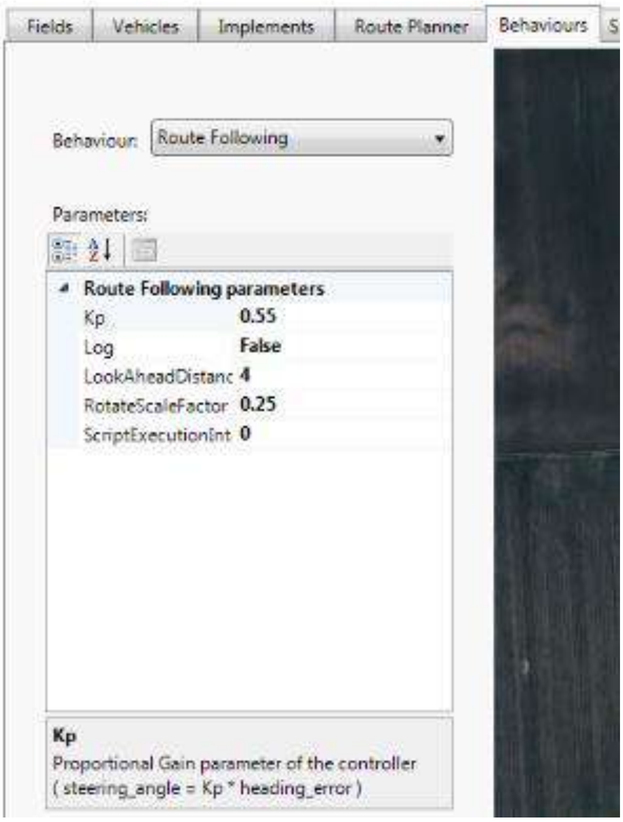
Once the route is created it can also be seen in the first tab (**Fields**) in Routes list. There it can be deleted or by pressing the **Edit Route** button, the user can change various parameters as seen in **Figure 106**.



WP	Northing	Easting	Tolerance	Speed	Mode	Task
1	4369936.81	624437.28	1.50	1.00	MXTE	Lift Cutters
2	4369954.22	624686.15	0.50	4.00	MXTE	Lower Cutt...
3	4369954.43	624687.49	1.50	1.00	STWP	Lift Cutters
4	4369954.82	624688.07	1.50	1.00	STWP	Lift Cutters
5	4369955.38	624688.47	1.50	1.00	STWP	Lift Cutters
6	4369956.05	624688.67	1.50	1.00	STWP	Lift Cutters
7	4369956.74	624688.62	1.50	1.00	STWP	Lift Cutters
8	4369958.71	624688.12	1.50	1.00	STWP	Lift Cutters
9	4369959.35	624687.84	1.50	1.00	STWP	Lift Cutters
10	4369959.85	624687.36	1.50	1.00	STWP	Lift Cutters
11	4369960.15	624686.73	1.50	1.00	STWP	Lift Cutters
12	4369942.81	624436.98	0.50	4.00	MXTE	Lower Cutt...
13	4369942.83	624435.62	1.50	1.00	STWP	Lift Cutters
14	4369943.14	624435.00	1.50	1.00	STWP	Lift Cutters
15	4369943.64	624434.52	1.50	1.00	STWP	Lift Cutters
16	4369944.27	624434.23	1.50	1.00	STWP	Lift Cutters

Figure 106: Route editor dialog

In the **Behaviours tab** the user can configure the properties of software's behaviours. At the moment only **Route Following behaviour** is available with the properties presented in **Figure 107**.



Behaviour: Route Following

Parameters:

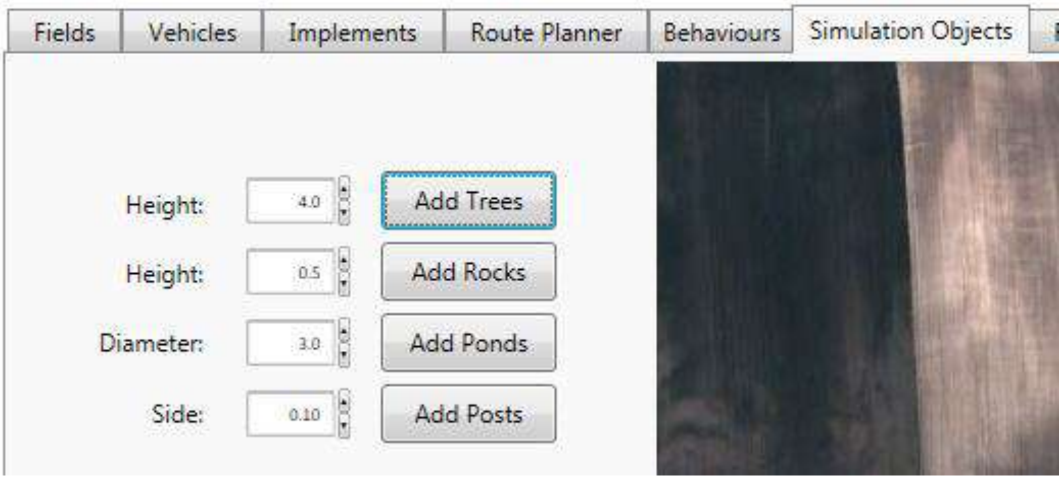
Route Following parameters

Kp	0.55
Log	False
LookAheadDistanc	4
RotateScaleFactor	0.25
ScriptExecutionInt	0

Kp
Proportional Gain parameter of the controller
(steering_angle = Kp * heading_error)

Figure 107: Behaviours tab

The user has the ability using the **Simulation Objects** tab to add trees, rocks, ponds and posts to the selected field (**Figure 108**). They will appear in the map as an icon related to the type of object.

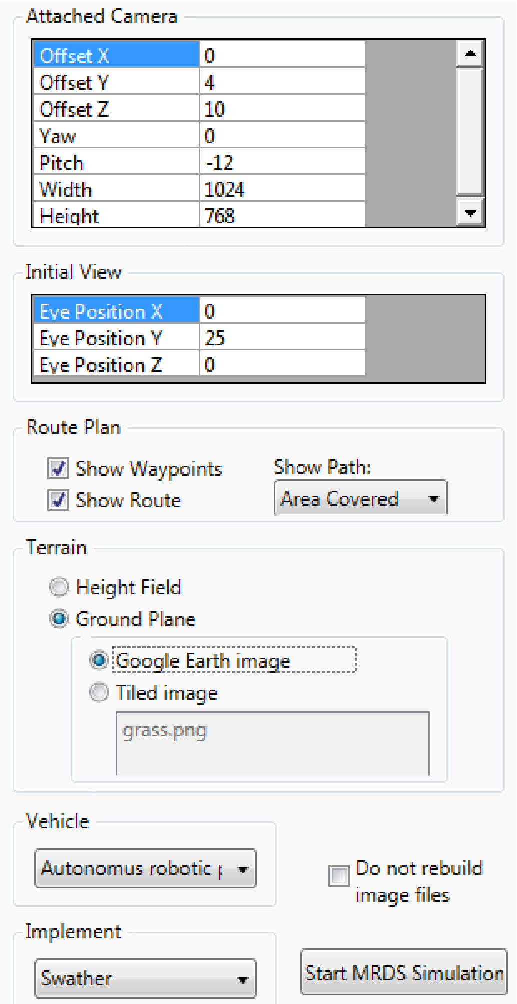


Height: 4.0
Height: 0.5
Diameter: 3.0
Side: 0.10

Figure 108: Simulation Objects tab

In the **Run Simulation tab** (**Figure 109**) the user can configure the following settings that will be used to run the MRDS simulation:

- **Attached camera**: Configuration of the relative position and orientation of the camera attached to the vehicle, as well as the width and height of the image.
- **Initial View**: Initial position of the main camera.
- **Route Plan**: Configuration of how the Route Plan will be shown in the simulation. The user can check/uncheck options for showing '**Waypoints**' and '**Route**' (lines joining the waypoints). Also, how the vehicle trajectory will be shown can be selected. Options are "**Area Covered**", "**Vehicle Track**" or "**None**".
- **Terrain**: Selection of the type of the surface: '**Ground Plane**' or '**Height Field**'. The second option will build a 3D terrain using the altitude values read from the Google Earth Plugin. If '**Ground Plane**' is selected, the user can choose the kind of image that will be mapped on top of the terrain: the Google Earth snapshot or a tiled picture.
- **Vehicle**: Finally, selection of the vehicle the user wants to simulate.



Attached Camera

Offset X	0
Offset Y	4
Offset Z	10
Yaw	0
Pitch	-12
Width	1024
Height	768

Initial View

Eye Position X	0
Eye Position Y	25
Eye Position Z	0

Route Plan

☑ Show Waypoints

☑ Show Route

Show Path: Area Covered

Terrain

○ Height Field

● Ground Plane

● Google Earth image

○ Tiled image

grass.png

Vehicle: Autonomus robotic p

☐ Do not rebuild image files

Implement: Swather

Figure 109: Run simulation tab

When a vehicle is available for operation, the user can use the **Run real-world tab** (**Figure 110**). Pressing the “**Start control of real vehicle**” button, the robot is ready to be controlled by the software in manual or in automatic mode.

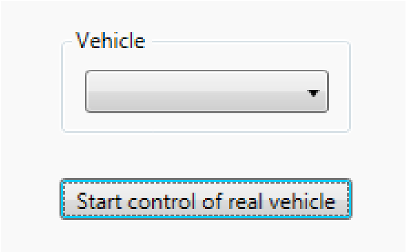
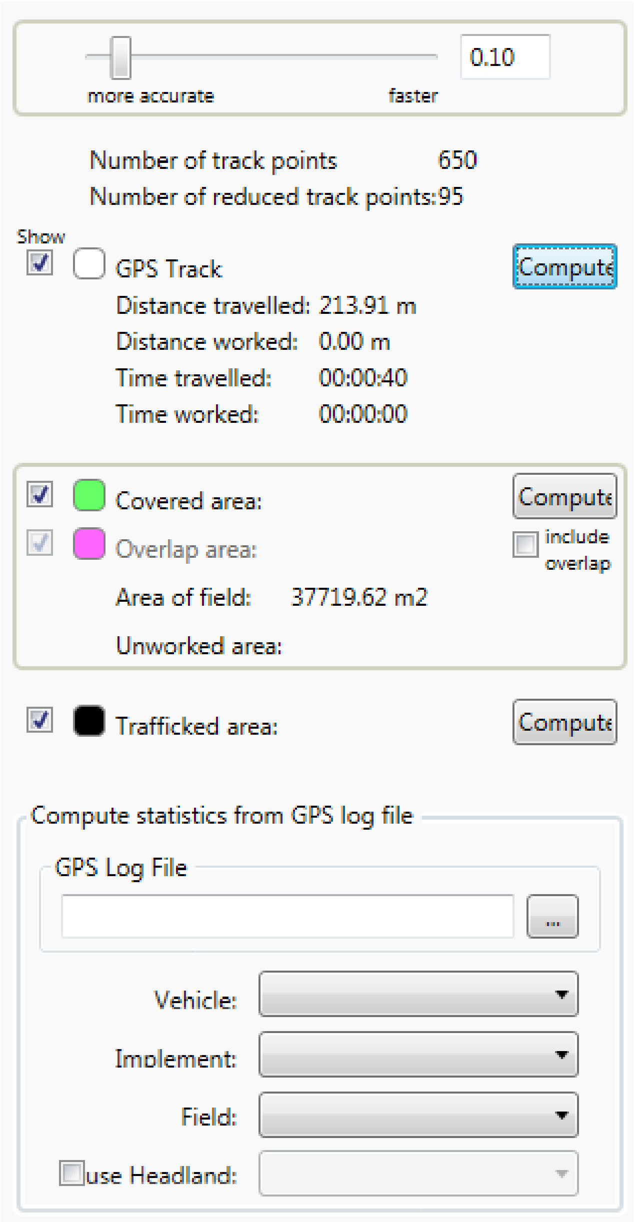


Figure 110: Run real-world tab

In the final **Stats Tab** (**Figure 111**) the user can have some information regarding the condition of the work performed by the vehicle in the specific field.



0.10

Number of track points 650
Number of reduced track points:95

☑ ☐ GPS Track
Distance travelled: 213.91 m
Distance worked: 0.00 m
Time travelled: 00:00:40
Time worked: 00:00:00

☑ 🟩 Covered area:
☑ 🟪 Overlap area:
☐ include overlap
Area of field: 37719.62 m2
Unworked area:

☑ ● Trafficked area:

Compute statistics from GPS log file
GPS Log File
Vehicle:
Implement:
Field:
☐ use Headland:

Figure 111: Statistics Tab

3.3.2.4 Simulation of route planning through MRDS simulation

The simulation is used for ensuring that the UGV will be able to follow the route properly without any possible error / multifunction that can create damage to the vehicle. As soon as the user presses the "**Start MRDS Simulation**" button the software outputs a message that it takes a snapshot of the selected field. This snapshot will be used as a picture of the surface of the field if the user hasn't selected a specific tiled image as described in a previous section.

After the generation of several files, the MRDS Visual Simulation Environment opens in a new window showing the field and the vehicle at the chosen gateway (**Figure 112**).

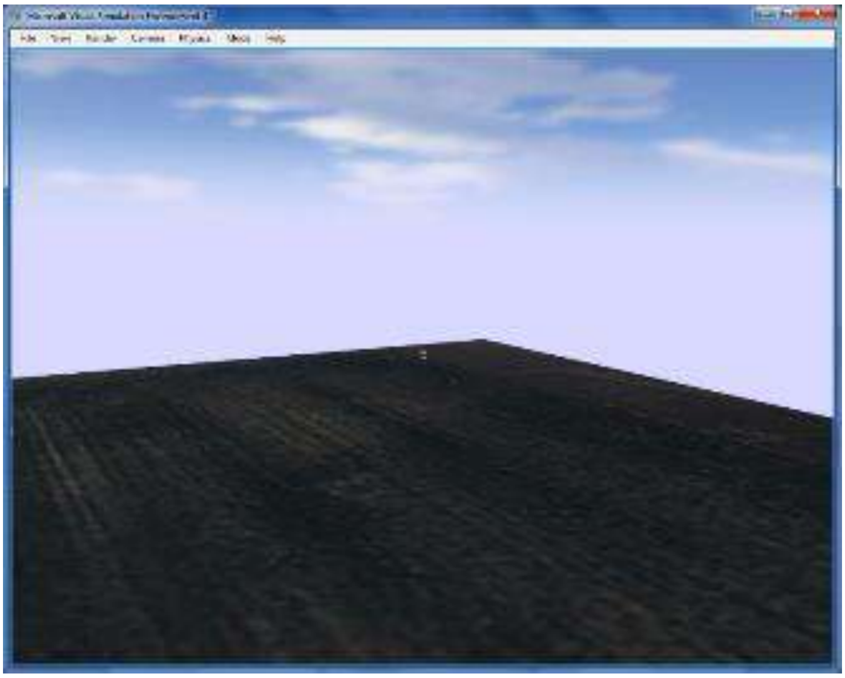
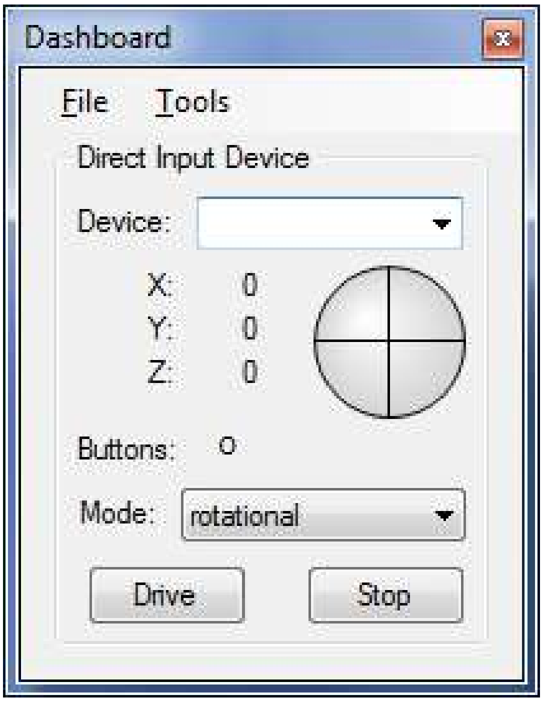


Figure 112: Initial view of MRDS

It also creates two new windows: the **Dashboard** (**Figure 113**) and the **Route Following**. Using the Dashboard the user can drive the simulated vehicle manually (pressing “**Drive**” button first).



Device:

X: 0

Y: 0

Z: 0

Buttons: 0

Mode: rotational

Figure 113: Dashboard

The user has the option to switch to the view from Vehicle’s attached camera (**Figure 114**).

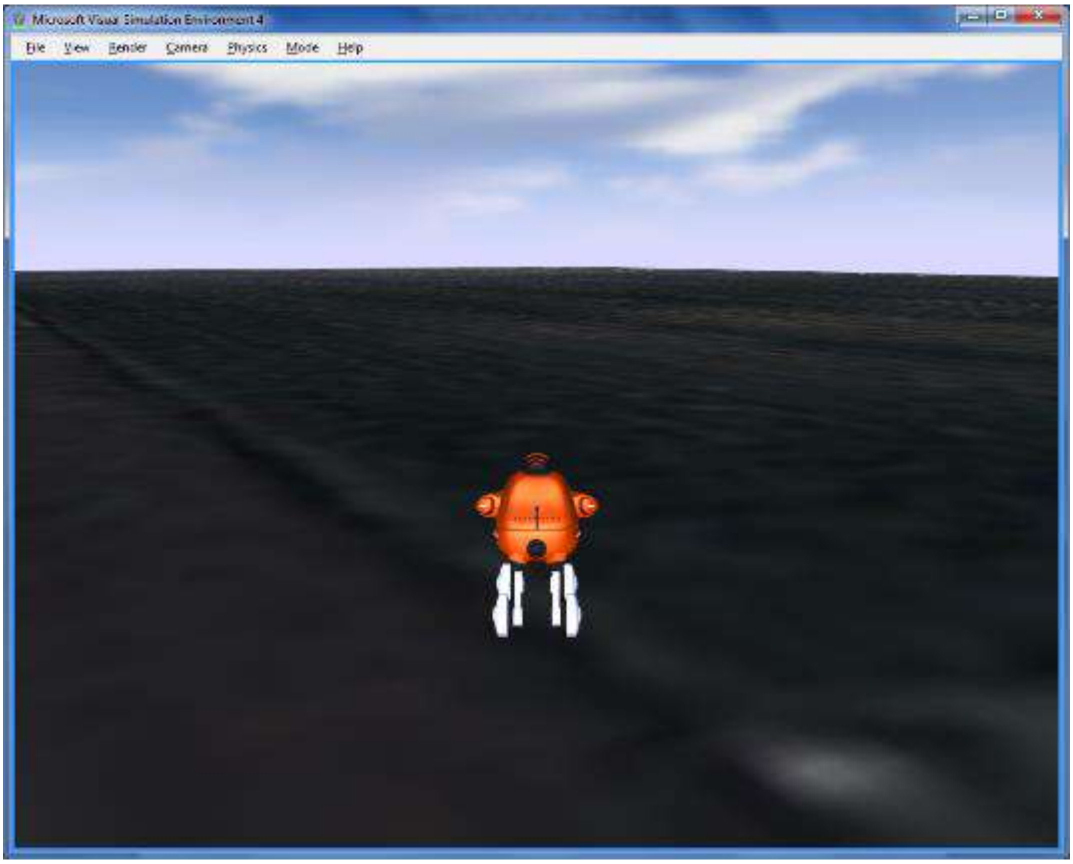
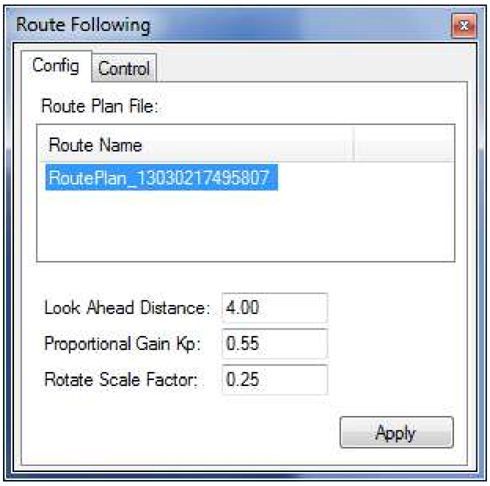


Figure 114: On board camera view

The **Route following service** shows the routes the user has created (**Figure 115**).



Route Plan File:

Route Name
RoutePlan_13030217495807

Look Ahead Distance: 4.00
Proportional Gain Kp: 0.55
Rotate Scale Factor: 0.25

Figure 115: Route following dialog

Choosing one of them and pressing the “**Apply**” button the route will be drawn in the MRDS Visual Environment after a few seconds as presented in **Figure 116**.

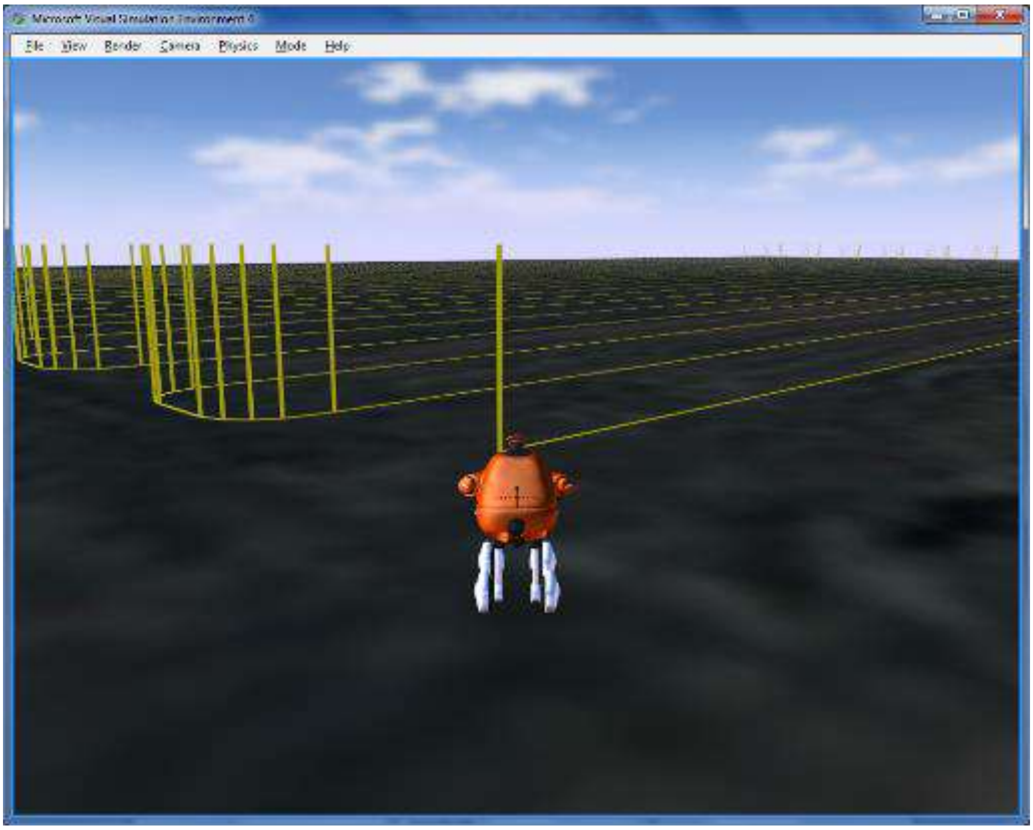
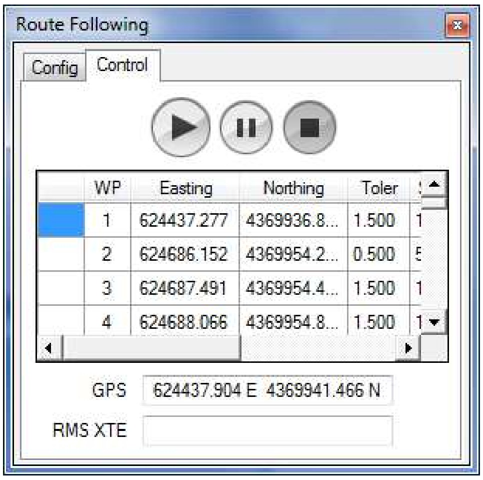


Figure 116: Applied route to the virtual environment

Going to the **Control tab** of the Route Following dialog and pressing the "**Play**" button (**Figure 117**) the vehicle will start to follow the route. The user has also the ability to pause and stop the procedure.



WP	Easting	Northing	Toler	
1	624437.277	4369936.8...	1.500	1
2	624686.152	4369954.2...	0.500	5
3	624687.491	4369954.4...	1.500	1
4	624688.066	4369954.8...	1.500	1

GPS 624437.904 E 4369941.466 N

RMS XTE

Figure 117: Control dialog

In **Figure 118** route following viewing from the attached camera is illustrated while in **Figure 119** the general view is presented.

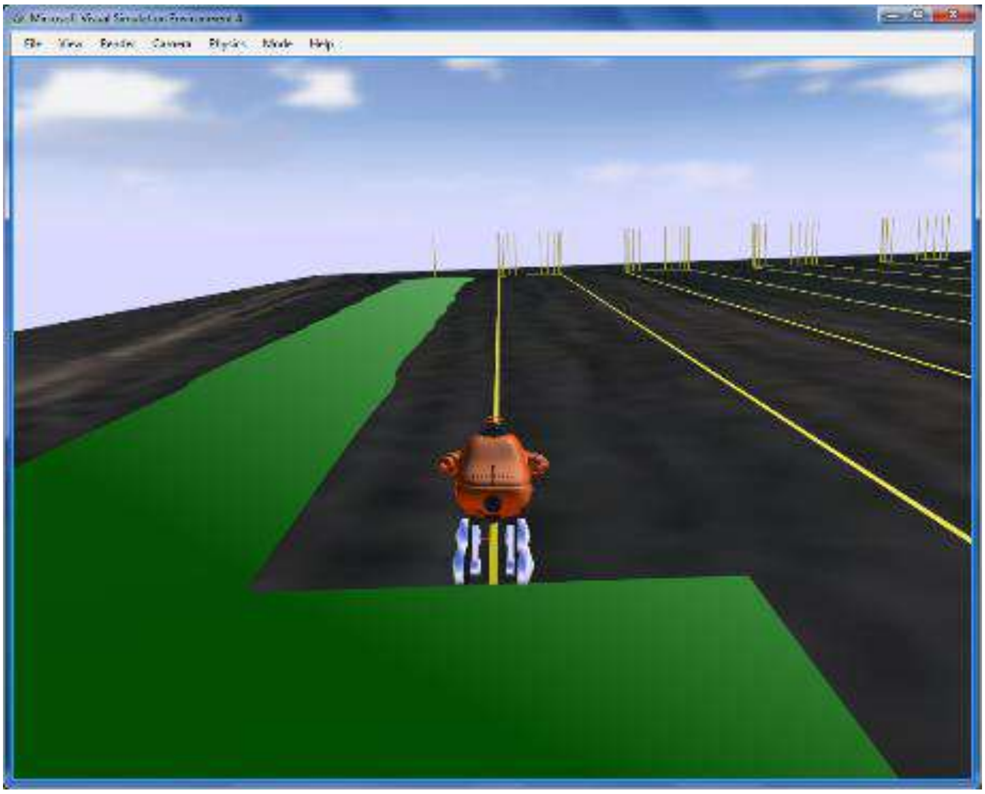


Figure 118: Vehicle following the route (attached camera)

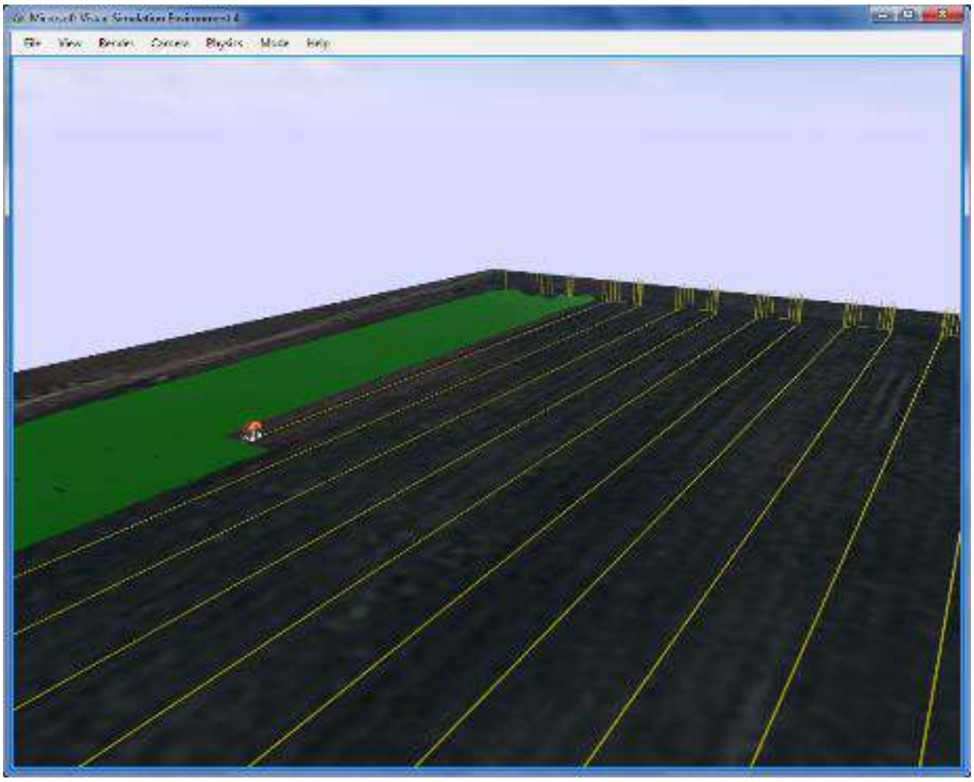
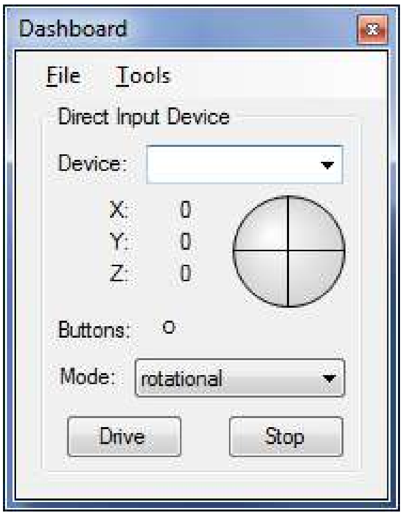


Figure 119: Robot following the route (main camera)

3.3.3 Results

3.3.3.1 Connectivity between UGV and the middleware, and control of UGV through middleware

The middleware can control the UGV through “**Run Real World**” tab. When user enables the real world function of the software, two new windows are appeared. The first one is the **Dashboard** (**Figure 120**) and the second one is the **route following** window (**Figure 121**).



Device:

X: 0

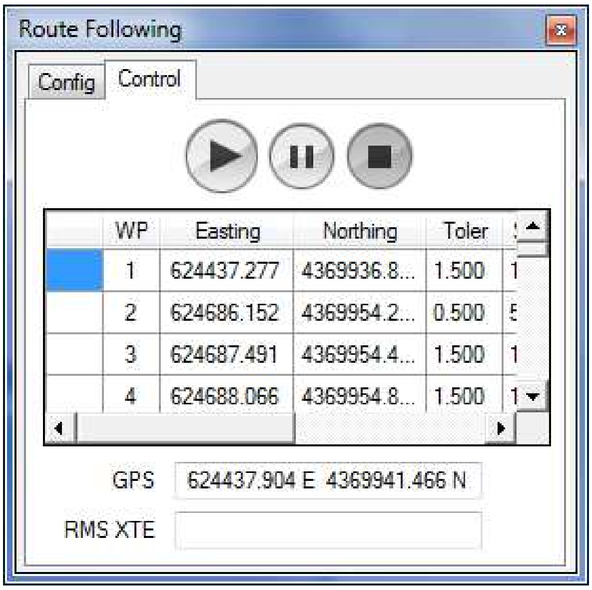
Y: 0

Z: 0

Buttons: 0

Mode: rotational

Figure 120: Dashboard



WP	Easting	Northing	Toler	
1	624437.277	4369936.8...	1.500	1
2	624686.152	4369954.2...	0.500	5
3	624687.491	4369954.4...	1.500	1
4	624688.066	4369954.8...	1.500	1

GPS 624437.904 E 4369941.466 N

RMS XTE

Figure 121: Route following window

Through the sphere of the **Dashboard**, user can give orders to the vehicle about front wheels steering angle and throttle position. The first task was to try the middleware and to see the string messages coming from it each time that the sphere position was changed. To do these 2 laptops were used. The first one had the middleware software installed, and he second one had the Hercules SETUP utility installed. Hercules SETUP utility (**Figure 122**) is a serial port terminal (RS-485 or RS-232 terminal), UDP/IP terminal and TCP/IP Client Server terminal and used for reading the middleware strings.

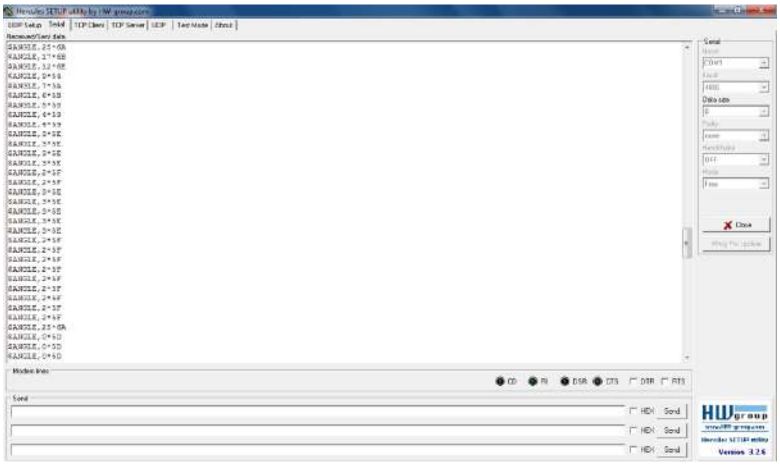
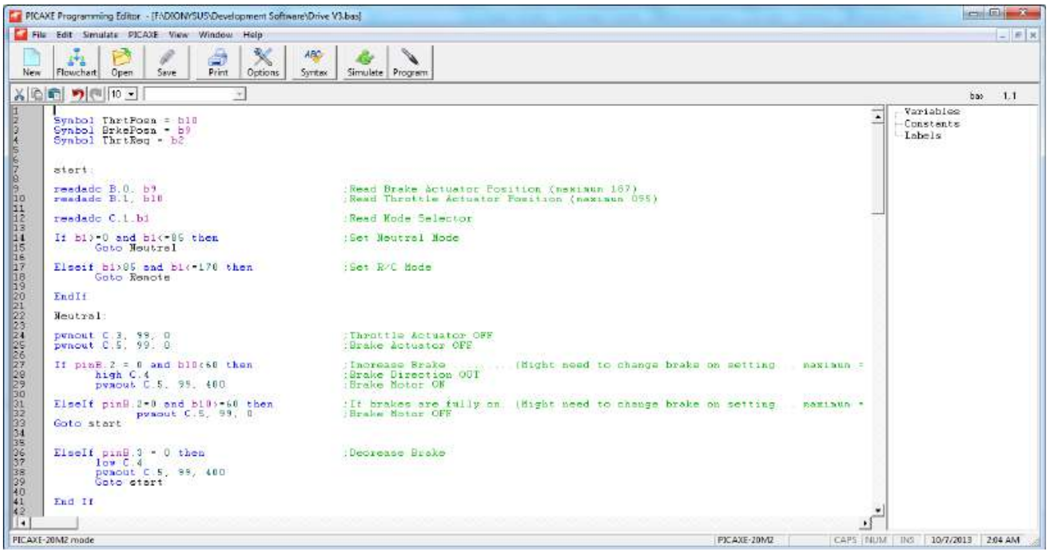


Figure 122: Hercules SETUP utility

The exact procedure of validation and evaluation of the middleware messages was: From the middleware computer, the sphere position was changing and the Hercules computer logged the middleware strings (**Figure 123**).

Figure 123: Checking middleware strings

The second task was to make possible the UGV to receive these strings, to read them, and to execute the appropriate commands (steering angle, throttle position etc.). For making this PICAXE programming editor was used (**Figure 124**).



```
Symbol ThrtPosn = b10
Symbol BrkePosn = b9
Symbol ThrtReq = b2

start:

readadc B.0, b9                                ;Read Brake Actuator Position (maximum 187)
readadc B.1, b10                               ;Read Throttle Actuator Position (maximum 095)

readadc C.1,b1                                 ;Read Mode Selector

If b1>=0 and b1<=85 then                       ;Set Neutral Mode
      Goto Neutral

Elseif b1>85 and b1<=170 then                  ;Set R/C Mode
      Goto Remote

EndIf

Neutral:

pwmout C.3, 99, 0                              ;Throttle Actuator OFF
pwmout C.5, 99, 0                              ;Brake Actuator OFF

If pinB.2 = 0 and b10<60 then                  ;Increase Brake ......... (Might need to change brake on setting .. maximum =
      high C.4                                 ;Brake Direction OUT
      pwmout C.5, 99, 400                      ;Brake Motor ON

ElseIf pinB.2=0 and b10>=60 then               ;If brakes are fully on..(Might need to change brake on setting .. maximum =
            pwmout C.5, 99, 0                  ;Brake Motor OFF
Goto start


ElseIf pinB.3 = 0 then                         ;Decrease Brake
      low C.4
      pwmout C.5, 99, 400
      Goto start

End If
```

Figure 124: PICAXE programming editor

PICAXE Programming Editor is an application for developing and simulating PICAXE BASIC language programs under Windows. The final code is written in BASIC programming language and the code for controlling the UGV throttle through the middleware is given below:

```
Symbol ThrtPosn = b10
Symbol BrkePosn = b9
Symbol ThrtReq = b2

start:

readadc B.0, b9                              ;Read Brake Actuator Position (maximum 187)
readadc B.1, b10                             ;Read Throttle Actuator Position (maximum 095)
readadc C.1,b1                               ;Read Mode Selector

If b1>=0 and b1<=85 then                     ;Set Neutral Mode
            Goto Neutral
Elseif b1>85 and b1<=170 then                ;Set R/C Mode
            Goto Remote
EndIf

Neutral:

pwmout C.3, 99, 0                            ;Throttle Actuator OFF
pwmout C.5, 99, 0                            ;Brake Actuator OFF

If pinB.2 = 0 and b10<60 then                ;Increase Brake .........(Might need to change brake on
setting .. maximum = 95)
            high C.4                         ;Brake Direction OUT
            pwmout C.5, 99, 400              ;Brake Motor ON
ElseIf pinB.2=0 and b10>=60 then             ;If brakes are fully on..(Might need to change brake on
setting .. maximum = 95)
            pwmout C.5, 99, 0                ;Brake Motor OFF

Goto start

ElseIf pinB.3 = 0 then                       ;Decrease Brake
            low C.4
            pwmout C.5, 99, 400
            Goto start
End If
```

```
If pinB.4 = 0 then                                      ;Increase Throttle
        high C.2
        pwmout C.3, 99, 400
        Goto start
ElseIf pinB.5 = 0 then                                  ;Decrease Throttle
        low C.2
        pwmout C.3, 99, 400
        Goto start
EndIf
Goto start

Remote:
        Pulsin C.6, 1, b2                               ;Read Remote control input
        if b2<135 then goto slow
        if b2>165 then goto fast
        if b2>135 and b2<165 then goto nothing

Autonomous:
If pinC.7 =1 then                                       ;Check Safety Input
        low C.2                                         ;Throttle Direction IN
        pwmout C.3, 99, 400                             ;Throttle Motor ON
;       high C.4                                        ;Brake Direction OUT
;       pwmout C.5, 99, 400                             ;Brake Motor ON
;       Goto start
EndIf

serin B.6, N4800, b11,b12,b13,b14,b15,b16,b17,b18,#b19
pause 10
b5=b9/20
;debug
sertxd("Middleware Throttle ")
b23=ThrtPosn b24=0 b25=0 b26=0
bintoascii b23,b24,b25,b26
sertxd(" Trrottle Posn ",b24,b25,b26)


b23=ThrtReq b24=0 b25=0 b26=0
bintoascii b23,b24,b25,b26
sertxd(" Throttle Request ",b24,b25,b26,13,10)

if b5<b19 then
goto fast
elseif b5>b19 then
goto slow
elseif b5=b19 then
goto nothing
endif

goto start

fast:
        high C.2                                        ;Throttle Direction OUT
        pwmout C.3, 99, 400                             ;Throttle Motor ON
        goto start

nothing:
        pwmout C.3, 99, 0                               ;Throttle Motor OFF
        goto start

slow:
        low C.2                                         ;Throttle Direction OUT
        pwmout C.3, 99, 400                             ;Throttle Motor ON
        goto start
```

After code creation a lot of testing was done at the laboratory, for checking the code and its efficiency (**Figure 125**).

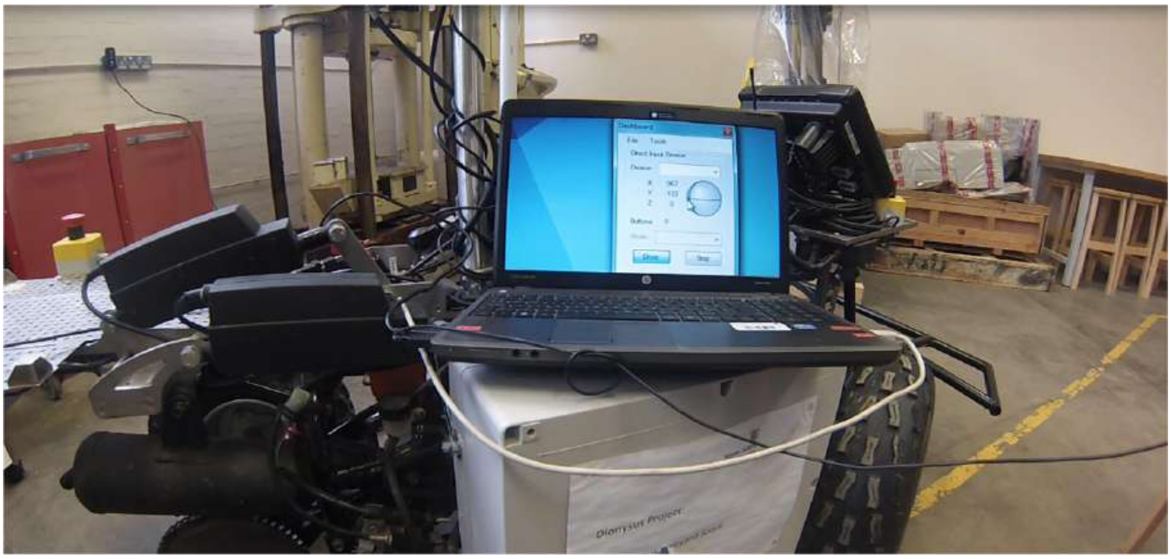


Figure 125: Demonstration of wheels and throttle movement through the middleware

3.3.3.2 Indoor testing

After the completion of the connectivity between the middleware and the UGV a lot of indoor tests were made before we make the first outdoor test. These tests had to deal, with connectivity, reliability and safety issues.

All systems and subsystems where checked for several connectivity parameters:

- **Connection Speed**: Maximum and minimum connectivity speed that can be achieved from each component.
- **Frequency of data update**: Test of the maximum frequency that a component can change its data (e.g. GPS position refreshing frequency).
- **Connectivity Errors**: Different combinations of connections setups where tested for finding any possible errors at the connection, or the connection strings.
- **Connectivity with different or external devices**: Connectivity ability with external devices or different devices (e.g. testing of various types and brands of GPS receivers).

Moreover, the systems and subsystems where checked for reliability factors:

- **Reliability over time**: Long duration constant function of each component to check their reliability over time.
- **Reliability with different operational parameters**: Change of systems parameters and analysis of their effects.
- **Reliability of the whole system**: Function of all the systems together and reliability tests over time, different conditions etc.

Safety issues analysis was the most important of indoor tests. The objectives of safety tests were:

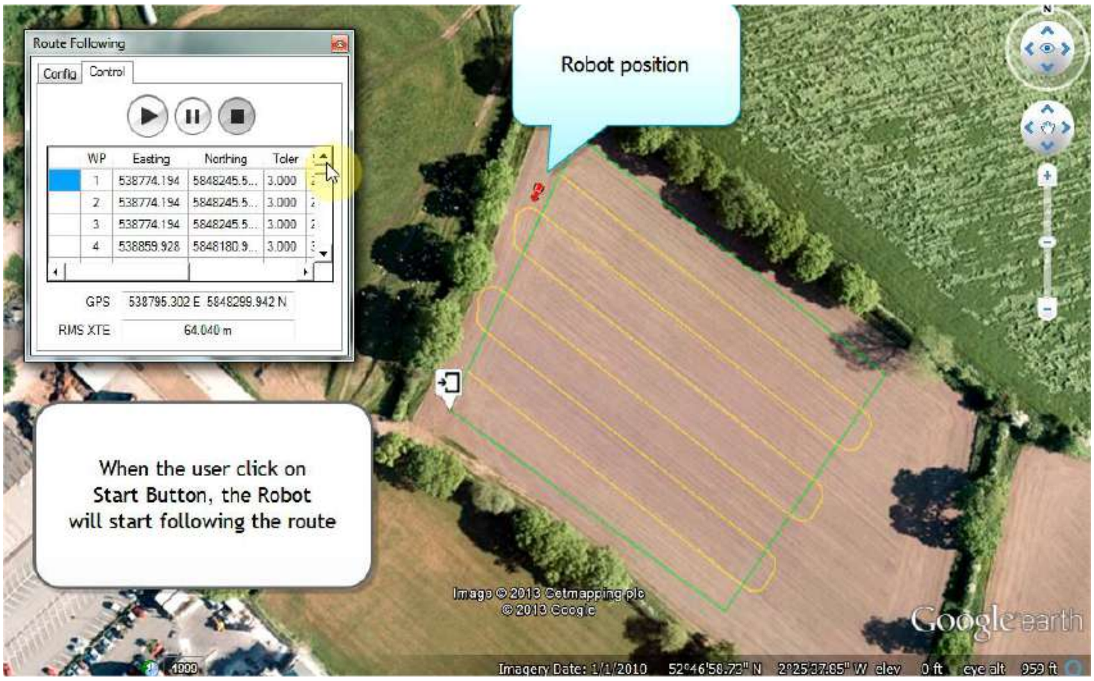
- To **check the parameters that could cause functional problems** on system or subsystems.
- To **predict any possible event** that could create safety issues.
- To **simulate the field environment** aspects and limitations.
- To develop or to improve existing **safety systems**.

3.3.3.3 Outdoor testing

The next step was to test the system on outdoor tests. The tests weren't so successful at the first tries and a lot of problems that wasn't predicted were experienced, which were related with the autonomous mode, as the robot was not able to keep a constant speed, or to move in a straight line. After some system modifications in all system components, the first successful tests were achieved (**Figure 126**).

Figure 126: Demonstration of fully autonomous robot

A lot of tests were held in various places with different proposed routes, and most of them were completed successfully (**Figure 127**).



Route Following

	WP	Easting	Northing	Toler
	1	538774.194	5848245.5...	3.000
	2	538774.194	5848245.5...	3.000
	3	538774.194	5848245.5...	3.000
	4	538859.928	5848180.9...	3.000

GPS: 538795.302 E 5848299.942 N

RMS XTE: 64.040 m

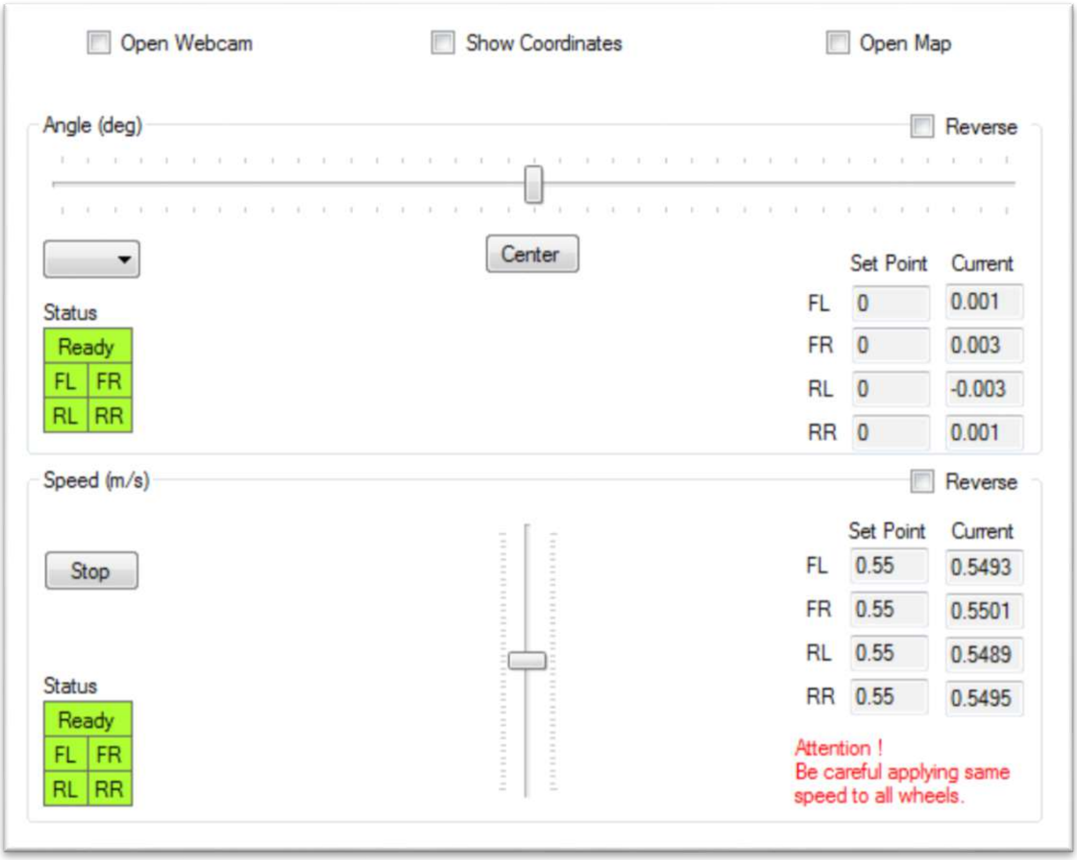
When the user click on Start Button, the Robot will start following the route

Figure 127: Middleware screen when controlling the robot

3.3.3.4 FMMIS for agricultural unmanned ground vehicles

For supporting agricultural robotics, the developed FMMIS incorporated one new additional module to address the needs for the autonomous vehicles, namely the **Control and Inspection Module**, which is used for controlling and inspecting the working parameters of the agricultural robots. The data transfer is made though the dedicated API that was developed for data and real time data transferring between the FMMIS and agricultural tractors and machineries. All the working parameters and all the sensors data are being stored in the FMMIS database, and they are accessible to the user at any time.

The results of the tests were satisfactory. For enabling the controlling of the robot through FMMIS in real time the user has to add the TCP/IP, User Name and Password information to the FMMIS. If there is no active connection, or some of the connection data are wrong, an error message will appear. **Figure 128** shows the control web page for controlling the autonomous vehicles. User can set up the **steering angle** and the **speed** of the unmanned vehicles by using the two slide bars or by setting the desired set points for each wheel separately. The status of each wheel is shown at the status tables at the left of the page, and the current values of speed and angle for each wheel is written at the textboxes at the right of the page. By clicking at the checkboxes at the top of the screen, **user can view video** from the robot's webcams, **view vehicle movement** in Google map and **view the coordinates** of the vehicle position.



Angle (deg)

	Set Point	Current
FL	0	0.001
FR	0	0.003
RL	0	-0.003
RR	0	0.001

Speed (m/s)

	Set Point	Current
FL	0.55	0.5493
FR	0.55	0.5501
RL	0.55	0.5489
RR	0.55	0.5495

Attention !
Be careful applying same speed to all wheels.

Figure 128: Controls for controlling the autonomous vehicle

Working in the open field environment, could create problems in the communication between the robot and the web server via the mobile internet connection. One of the parameters that the user has to set up through the FMMIS, is robot's priorities/options in case that the communication between the robot and the FMMIS will be lost. These options are:

- **Keep Working**. In that case, the agricultural unmanned vehicle will continue its task, but in case that it will be 10cm deviated of the proposed route, it will stop its movement and operation. All the data of the working parameters and from the sensors are stored temporally at the robot, until the connection restores.
- **Stop Working**. In that case the robot will stop working until internet connection restores.

In case that the mobile internet connection speed is too low, then, only the tools for controlling the robot, for the position of the robot, and for the robot alerts are working. All the other tools (e.g. webcam streaming) are becoming unavailable until the mobile connection speed becomes faster.

Moreover, the FMMIS cooperates with the middleware software via a dedicated API for the creation of the robots optimal route in the fields, the 3D simulation of the route following by the robots, and the statistical analysis of their movements.

The dedicated module that developed at the FMMIS can project the following information:

- **Fields and Boundaries**: This tool projects field maps and its boundaries which were drawn in the middleware, and a table with their coordinates (**Figure 129**).
- **Vehicles**: All robots details that belongs to the farm.
- **Implements**: The details of the implements or the sensors installed on robot.
- **Created Routes**: Middleware's created routes for each field and details for each route waypoint (**Figure 130**).

Field Name	X	Y	GeId
Sample_Field	-2.4251956939697266	52.782527923583984	13092221022162
Sample_Field	-2.4239296913146973	52.781974792480469	13092221022426
Sample_Field	-2.4231922626495361	52.782623291015625	13092221022564
Sample_Field	-2.4246022701263428	52.783275604248047	13092221022690

Figure 129: Field and boundaries projection

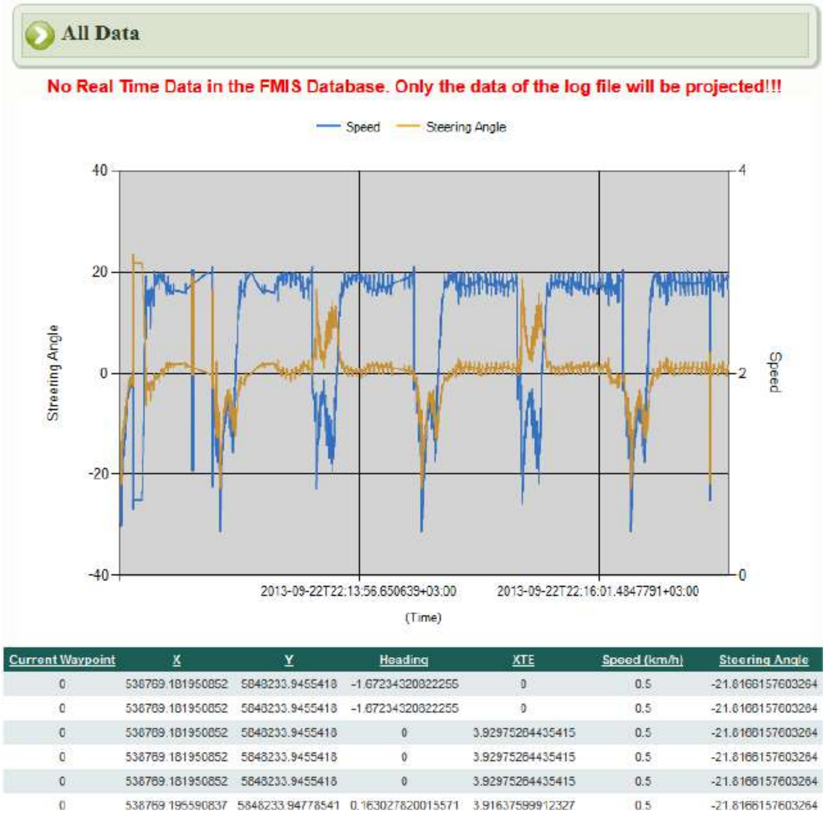
Route Name	X	Y	Geld	Number	Tolerance	Speed	Mode	Task
RoutePlan_13092221054139	-2.42511292315134	52.782632214385607	130922210541390	1	3	2	STWP	Lift Cutters
RoutePlan_13092221054139	-2.42511292315134	52.782632214385607	130922210541391	2	3	2	STWP	Lift Cutters
RoutePlan_13092221054139	-2.42511292315134	52.782632214385607	130922210541392	3	3	2	MXTE	Lift Cutters
RoutePlan_13092221054139	-2.4238495260729493	52.782045293875456	130922210541393	4	3	3	MXTE	Lower Cutters
RoutePlan_13092221054139	-2.4238127280563755	52.782031158203168	130922210541394	5	3	2	STWP	Lift Cutters
RoutePlan_13092221054139	-2.4237906044659843	52.782029401959953	130922210541395	6	3	2	STWP	Lift Cutters
RoutePlan_13092221054139	-2.4237688244402165	52.782032339629808	130922210541396	7	3	2	STWP	Lift Cutters
RoutePlan_13092221054139	-2.4237500149654339	52.782039616887282	130922210541397	8	3	2	STWP	Lift Cutters
RoutePlan_13092221054139	-2.4237058106668781	52.782083984274308	130922210541398	9	3	2	STWP	Lift Cutters

Figure 130: Created routes

Moreover, this module is responsible for projecting data and charts from the robot working parameters. The parameters projected are:

- **Robot Speed**: Show charts and data tables of robot speed during its route in the field.
- **Robot Steering Angle**: Show charts and data tables of robot steering angle due to its route in the field.
- **Robot Heading**: Show charts and data tables of robot heading due to its route in the field.

- **All Collected Data**: Shows charts and tables of all the collected robot working parameters and the measurements of its installed sensors (Figure 53).
- **Control Robot Example**: It gives a small example to the user about the controls that are being enabled when FMMIS controls the robot.



No Real Time Data in the FMIS Database. Only the data of the log file will be projected!!!

Current Waypoint	X	Y	Heading	XTE	Speed (km/h)	Steering Angle
0	538769.181950852	5848233.9455418	-1.67234320822255	0	0.5	-21.8166157603264
0	538769.181950852	5848233.9455418	-1.67234320822255	0	0.5	-21.8166157603264
0	538769.181950852	5848233.9455418	0	3.92975264435415	0.5	-21.8166157603264
0	538769.181950852	5848233.9455418	0	3.92975264435415	0.5	-21.8166157603264
0	538769.181950852	5848233.9455418	0	3.92975264435415	0.5	-21.8166157603264
0	538769.195590837	5848233.94778541	0.163027820015571	3.91637599912327	0.5	-21.8166157603264

Figure 131: Robot data after an agricultural operation

3.3.3.5 Validation and evaluation of indoor and outdoor test results

Through indoor and outdoor tests a procedure of evaluating and validating test results was held. This procedure was accomplished with 3 different ways. These were:

- Observations
- Middleware's simulation and statistics functions
- Farm Machinery Management Information System (FMMIS)

Observations were made by checking the system mostly on outdoor field tests. Whatever seemed not to be working right or efficiently was recorded, and actions in order to improve the system for the next test were taken.

The middleware expect of the ability to create optimal routes and to control the robot, has a 3D simulation function through MRDS which helps to simulate every route, by selecting the desired route, robot and system parameters. Additionally, it has a statistic tool which helps the evaluation of the efficiency of the route following by the robot (**Figure 132**).

0.10

Number of track points 5212
Number of reduced track points:216

☑ ☐ GPS Track
Distance travelled: 800.42 m
Distance worked: 687.00 m
Time travelled: 00:07:46
Time worked: 00:06:27

☑ 🟩 Covered area: 8839.29 m2
☑ 🟪 Overlap area: 119.85 m2
☑ include overlap
Area of field: 10017.27 m2
Unworked area: 1177.98 m2

☐ ● Trafficked area: 382.13 m2

Compute statistics from GPS log file
GPS Log File
Vehicle:
Implement:
Field:
☐ use Headland:

Figure 132: Route following and efficiency

This validation and evaluation procedure led to the following improvement of the middleware and the unmanned vehicle. The major improvements after the validation and evaluation procedure where:

Development of a modified transmission system: The robot was developed using a commercial vehicle basis. The maximum speed of the original vehicle was up to 50km/h. That maximum speed had to be reduced, for making robot capable of moving with very small speeds that needed for achieving in success the various agricultural operations as well as for security reasons.

Radio transmitting “dead’s man handle” was a safety system that was developed from the beginning. If the red button was not pushed the robot engine did not work. Through the testing procedure, it was proved, that that flow logic it could create safety problems. For this reason “dead’s man handle” was designed from the beginning.

Speed limiter: Despite the development of a modified transmission system, the robot proved to have a quite big maximum speed. For that reason a speed limiter code was developed and installed into its Drive ECU.

Safety bumper: After a small crash that was experienced in one of the initial tests, caused by a middleware bug, an improved safety bumper has designed for preventing the vehicle for possible damages.

I am alive string: After the first outdoor tests it was proved that there wasn't developed any safety rule, for any possible middleware bug or crash. For this reason, a new message string which informs robot ECU when the middleware works normally, was developed. When the robot doesn't receive that message for over a second, then automatically stops. This functionality was added also in the FMMIS in the case that the user is controlling the system through it.

Route efficiency was also improved. An example is being given below: Left part of **Figure 133** shows a route following test at the first tests, while right part shows a route following test after some system modifications. With a more analytic view it can be seen very clearly the improvement that was made at the covered working area from an installed to robot implement.

First Tests

After system Improvments

Figure 133: Covered area improvements

3.3.4 Discussion and conclusions

The principal characteristics for prototype UGVs are the light weight, small size and energetic autonomy (Blackmore & Fountas, 2007)[188]. Light weight means that the vehicle requires lower energy and induces less soil compaction while the vehicle must be small for safety reasons, for achieving higher precision on the tasks execution and having bigger maneuverability within the field, minimizing turning time lags.

The mechanical design of the prototypes depends on the main tasks that the vehicle has to carry out. For achieving the maximum manoeuvrability which is a very important for autonomous vehicles and for being able to work to different type of crops and for maximum flexibility, many agricultural robotic prototypes have variable track width and height configuration. Problems with this type of approach have been reported as vehicle’s center of gravity, especially when the height is increasing, which make prototypes unstable at slopes.

Power sources for agricultural robots that are commonly used on prototypes are petrol engines or electric motors. Electric motors are environmental friendly, but they increase the weight of the robots (load of batteries) and have small autonomy, while petrol engines are having more power output are totally depended on fossil fuels. For that reason the selection of power source depends on prototypes tasks, use, and design.

For the development of the UGV, a commercial ATV was used for providing the necessary ability to efficiently move into the fields, and to provide enough payload capacity in order an implement to be able to be attached on it for making it able to execute agricultural operation using small agricultural machineries. It can be mentioned that the UGV is able to move efficiently into the harsh agricultural environment (including steep slopes), having compact design and achieving small ground compaction. It has the ability to carry >100 kg of payload such as sensors, processing units and implements (e.g. spraying equipment), and work for more than 5 hours constantly without refuelling. Moreover, it has safety mechanisms both in terms of software and hardware (e.g. stop switches). Finally, it can communicate wirelessly for sending and/or receiving information and for remote controlling.

The developed middleware was tested in a wide range of field types with different geometries utilizing different vehicles and implements and in all cases it was proved that the vehicle followed the calculated route. The simulation is even more realistic as the user has the option to build a 3D terrain using the altitude values read from the Google Earth Plugin. A great advantage of the proposed software is that it uses an advanced physics simulation engine (the NVIDIA^{TM} PhysX^{TM} Technology 3D engine), enabling real-world physics simulations for robot models projecting any possible errors on their route planning, causing the vehicle even to turnover or stop when the user chooses parameters out of reasonable limits (e.g. high turning speed).

Furthermore the middleware was developed to be able to control the vehicle’s hardware in the demanding field conditions communicating by a CAN bus using the ISO 11783 protocol. It is also capable of transmitting data over the internet in a format that follows current standards (e.g. XML, JSON). By this way exchange of data with the FMMIS is achieved.

The FMMIS has been extended and includes a dedicated module for managing the farm and at the same time to control and store data from agricultural robots, with very satisfactory results. The FMMIS with its ability to embed agricultural robots functionalities, can contribute to mitigation of climate change by decreasing greenhouse gas emissions. Specifically, the decrease in fuel consumption (compared to agricultural tractors) will decrease greenhouse gases emissions. As a result, the FMMIS is in accordance with the Sustainable Development Goals that promote the adoption of sustainable practices in agricultural production that mitigate drivers of climate change.

Moreover, such systems can replace heavy vehicles in agricultural activities. Repetitive heavy vehicles passes for agricultural operations lead to soil compaction: the reduction of soil volume as soil particles are pressed together by external forces, including heavy machinery. Soil compaction is highly detrimental to agricultural production and lowers yields by i) limiting root growth and the capacity for water and nutrient uptake, ii) causing difficulties with soil cultivation and seedbed preparation, iii) decreasing the penetration of rain or irrigation water, iv) causing a decline in soil structural stability and v) causing a decline in fertilizer efficiency as compacted soil provides few surfaces to retain and release fertilizer. In addition a compacted soil requires more horsepower and fuel to cultivate. Planting implements are less effective in compacted soil and germination is poor. Soil compaction is the main form of land degradation, affecting more than 11% of land area globally[189]. Technologies that use sustainable processes and decrease water use, ecotoxicity and soil compaction need to be adopted.

The proposed FMMIS for agricultural robots directly addresses the requirements set by the Strategic Research Agenda (SRA) and the Robotics 2020 Multi-Annual Roadmap (MAR) in agricultural robotics. The financial viability of agricultural holdings is among the top priorities of EU, as reflected in the Common Agricultural Policy (CAP). By considering the farm as an enterprise and by taking into account the fact that heavy machineries usage is a core and costly process in all farms, operational and financial benefits resulting from the wide adoption of such approaches.

3.4 Design and development of a low cost IoT node for Precision Agriculture

3.4.1 Introduction

A complete FMMIS must support data from tractors, implements, unmanned vehicles, sensors installed at the various implements/vehicles, as well as in situ sensors. For making a holistic FMMIS, the design and development of a low cost IoT node for retrieving in-situ measurements and for automating agricultural operations took place.

According to Carli and Canavari[190], the data flow on PA is based on three main processes. Namely: data collection, information processing and decision making.

The main sources used in PA for **data collection** are: (i) Sensors, (ii) Satellite data, (iii) Laboratory measurements and (iv) In situ manual measurements. From the aforementioned data sources, only sensors can be considered as IR4 technologies, as they are one of the main four distinct components of IoT (*sensors/devices, connectivity, data processing, and a user interface)*. Following industry 4.0 revolution, a big variety of low cost processors, controllers, electronic components and sensors are now available, that can be used for developing low cost IoT solutions. A great example is Arduino open-source microcontroller based-development boards[191]. These boards provide, at a very low price, all the characteristics needed for developing a monitoring/actuating device namely an embedded microprocessor, connections for power supply, analogue and digital I/O channels for interfacing with peripheral devices (e.g. sensors), dedicated channels (e.g. USB communication port), and a vast variety of different modules for various purposes (e.g. GSM modules), which allows the implementation of systems with extended interoperability and extendibility as these boards are compatible with almost any hardware protocol (e.g. RS485, Modbus, CANBus etc). In addition, the extensive usage of Arduino boards, with a huge community and support, made these boards mature with great reliability and flexibility which is necessary for PA applications, as the availability of timely and high quality data is the basis for the enhanced decision making needed at the production process. For this reason, a lot of research has been reported the last years on developing Arduino based solutions for agriculture[192,193,194] as well as in other domains as air quality[195,196,197] and water monitoring[198,199]. In addition, the extensive use of Arduino boards, contributed on the development and availability in the market of a variety of low cost sensors. As these sensors can be applied for monitoring the agricultural environment, the efficiency of using low cost sensors in agriculture have been studied by many researchers[200,201,202] with positive results.

As mentioned above, IoT, cloud as well as big data and analytics technologies will play a critical role for the transition of agriculture to the new era. Proceeding into **the elaboration of the information**, a critical aspect is the data transmission to the cloud. As agriculture is held in open environment, wireless data transmission from devices with low energy consumption is required, as in most of the cases there is not a power source or wired internet connection available at the fields. Nowadays many different types of wireless data communication protocols are used in agriculture[203]. Some of them are broadband cellular network technology protocols (GPRS, 4G, 5G), LPWA - Low Power Wide Area Network protocols (LoRaWAN, SigFOx, NB-IoT, LTE-M), WLAN - wireless LAN protocols (Wi-Fi) and IEEE 802.15 Protocols (ZigBee, Bluetooth). Each one of them has its advantages and disadvantages in terms of power consumption, coverage range and data collection rate. Therefore, in order to collect and transmit data, use of an appropriate device to retrieve and transmit the measurements is needed. A typical wireless node for agriculture consists of the microcontroller which is also capable of performing some processing, the transceiver which is responsible for the wireless communication, the power source and finally the various circuits needed (e.g. ADC converters) for supporting the reading of analog and digital signals of the sensors and the actuators.

Agricultural ecosystem is a complex system with many parameters affecting it which makes a necessity for farmer to emphasize into the **decision making process**. The use of new IoT technologies can create large quantities of data[204]. The capabilities given by the cloud, the big data and analytics technologies, can help on retrieving and analysing agricultural data in an efficient and timely way, allowing the development of Decision Support Systems (DSS) that can run complex algorithms and helping farmers on decision making[205]. Moreover, the use of machine learning and Artificial Intelligent (AI) can contribute on improving the decision making process as they can be used for creating better models (for example disease prediction models and infection level analysis) resulting to better decisions and improved farm management[206,207].

The aim of this research was to design and implement a low cost IoT system for agriculture that will feed the FMMIS with accurate data and will be able to automate various in situ procedures. As the complexity of the systems and farmers familiarity with innovations are factors affecting PA adoption rate, an IoT system must have easy installation and configuration process. At the moment most IoT systems for agriculture are quite complicated, need specialized knowledge and/or even some training. This is mainly due to the need of configuring the typical star topology (sensor nodes - gateway node) for transmitting the data to the cloud, as the most common communication protocols that are used in agriculture are based on that topology (e.g. LoRaWAN). The use of such protocols offers big advantages in terms of power saving and cost of connectivity, but their major disadvantage is the need of configuring the connectivity parameters between the getaway and the sensors nodes.

Moreover, an agricultural IoT node must be energy autonomous, to be compatible with a vast number of sensors and the necessary protocols for supporting them, and finally it must have a compact size and able to work efficiently into agricultural harsh environment. A typical wireless node for agriculture has at least IP65 protection (water and dust resistant), and consists of the microcontroller which is also capable of performing some processing, the transceiver which is responsible for the wireless communication, the power source and finally the various circuits needed for supporting the reading of analog and digital signals of the sensors.

Finally, an appropriate IoT system for agriculture should have a very low final price, providing to the farmers a high Return on Investment ratio (ROI), helping them on increasing their profitability even from the 1st year of operation enabling them to understand cost / benefits and increasing their wiliness to invest on it. For this reason, the system must be equipped with low cost sensors which will be able to provide measurements with high accuracy. For achieving this, a careful calibration must be carried out, which is something also needed when using conventional commercial instrumentation[208].

3.4.2 Materials and Methods

The IoT node was designed and developed using Arduino architecture (**Figure 134**), as it has a very low price for all the components needed for developing a low cost IoT system. A typical wireless node consists of a **microcontroller** that is also capable of performing data processing; the **transceiver**, which is responsible for the wireless communication; the **power source**; and finally the various **circuits** needed (e.g., AD converters) for supporting the reading of analog and digital signals of the sensors and the actuators. To implement the node, a board was developed by splitting it into 4 distinct layers:

- The power management layer, which was designed using methodologies for minimizing power consumption.
- The interfacing layer, responsible for the connectivity of peripherals (sensors and actuators) with the system.

- The processing/controlling layer, responsible for the initial data processing.
- The connectivity layer, responsible for the data transmission to the FMMIS.

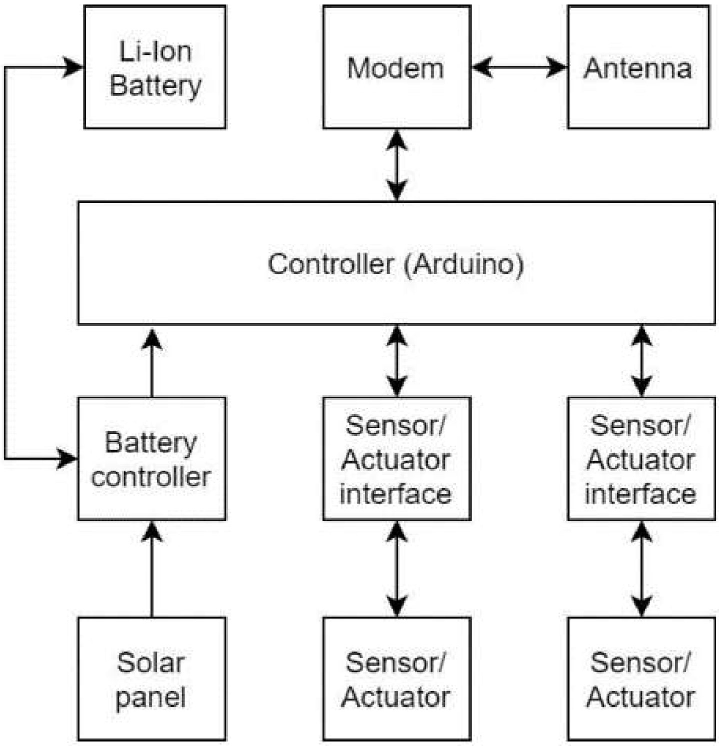


Figure 134: IoT node architecture

The node (**Figure 135**) has a small size of 12 × 8 cm and IP67 protection so that it can be used in a large number of applications in harsh environments. Moreover, it supports both analog and digital sensors and various communication protocols (e.g., RS-485 serial communication protocol) for supporting most of the available sensors/actuators (even industrial ones).

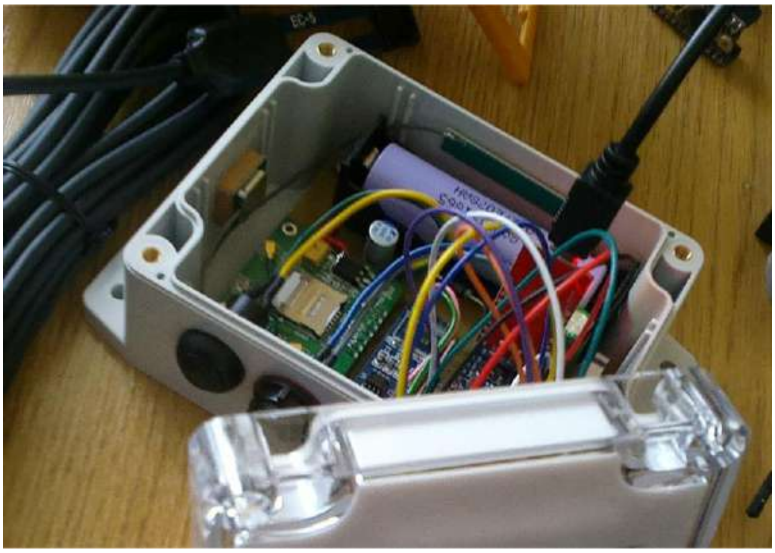
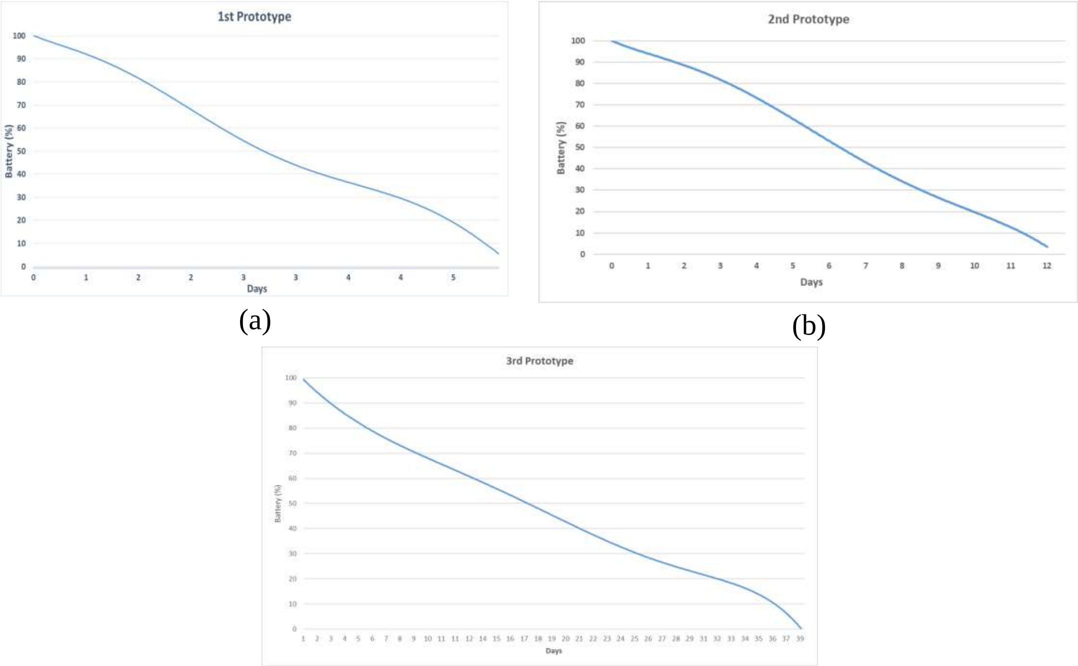


Figure 135: IoT node implementation

Data can be uploaded using general (GPRS and 4G) or low-power (NB-IoT and LTE-M) cellular network communication protocols. The communication between the node and the FMMIS was bidirectional in order to enable remote control and configuration of the system (e.g., open/close valve), and it achieved almost real-time measurements with a minimum sampling rate of 30 s.

To avoid the configuration process on behalf of the user, making the system "plug and play" and able to work with the simple click of the start button, it was decided that the developed node should also act as a getaway node, with direct communication to the FMMIS. Using this methodology, the nodes were preconfigured, while the FMMIS was developed in such way to make them capable to automatically understand the type of the sensors connected to each node.

The power consumption of an IoT system is a quite critical parameter, as there are cases in which sensors have to be placed into dense and high crops (e.g., maize), where the charging of batteries is a difficult task. To minimize the power consumption of the node, 3 different prototypes were developed. The first one was developed using a commercial Arduino board, while the second was developed by designing a custom board for reducing power consumption. The third one (**Figure 135**) was an update of the second prototype, which was developed by enhancing the board design for minimizing the power consumption even more. **Figure 136**, presents the energy autonomy of the 3 prototypes at a data transmission rate of 10 minutes.



(a)

(b)

(c)

Figure 136: Energy autonomy of the 3 prototypes at a data transmission rate of 10 minutes. (a) 1st prototype: 5.5 days, (b) 2nd prototype: 12 days, (c) 3rd prototype: 39 days

The autonomy of the system is increasing as the sampling/transmitting rate of the data is being increased. **Figure 137** presents the autonomy (in days) of each prototype, for different sampling/ transmitting rates.

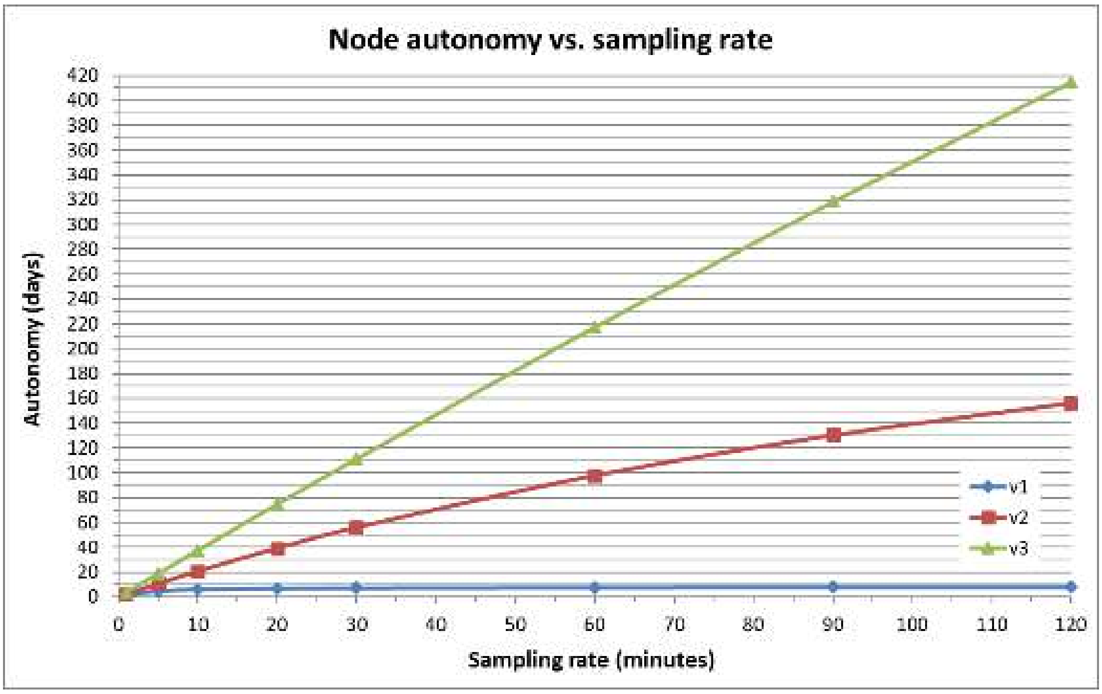


Figure 137: Energy autonomy in days of the 3 prototypes for different sampling rates

With a sampling rate of one hour, the node has an energy autonomy of approximately 210 days, which is acceptable in most cases of agricultural monitoring (e.g. soil moisture measurements). This makes the IoT node ideal for using it at any annual crop, as it can work during the cropping period without using any power source for recharging. In case that more intensive measurements are needed, a solar panel smaller that 1W is enough to provide to the node the energy required for its operation.

As there are low-cost sensors that are able to provide measurements of high accuracy with a careful calibration or by using deep-learning-based sensor modelling, more than 80 different sensors were tested and evaluated to select the ones with the lowest price in combination with the highest accuracy and durability. In the case of the ones that passed these functional tests, in some cases (pH, temperature, and turbidity sensors), modifications were made to increase their accuracy and make them waterproof. Waterproofing was achieved by potting the sensitive electrical/electronic parts, wiring, and connections of the aforementioned sensors using epoxy resin. Moreover, as the majority of the low-cost sensors were OEM-branded operating using circuits developed from multiple manufacturers (e.g., TDS, pH, and Ultrasonic level sensor), new circuits were developed and embedded into the IoT node for ensuring the proper functionality of the low-cost sensors as well as their measurements' accuracy. The sensors that have been supported by the IoT node are:

- **Weather measurements**: Temperature, humidity, atmospheric pressure, precipitation, wind speed, wind gust, wind direction, solar radiation, and UV index.
- **Soil measurements**: Moisture content, temperature, pH, and electrical conductivity.
- **Water measurements**: Temperature, pH, electrical conductivity, turbidity, TDS, water flow, and storage tank level.

To enable remote control and automation, the communication between the node and the FMMIS was bidirectional, and the actuation could be achieved by remote control through a website in which the user can:

- Open or close an actuator.
- Enter the thresholds of an actuator to change its state (e.g., specific temperature and water level).
- Enable autonomous operation (e.g., applying precision irrigation).

The ability of the system to efficiently monitor agricultural environment and to automate agricultural operations (in this case irrigation scheduling), was evaluated at different pilot sites Field trial tests included the evaluation of:

(i) sensors' accuracy,
(ii) system's monitoring capabilities and
(iii) automated irrigation scheduling efficiency

3.4.3 Results

Climate is the most important factor in decision making in agriculture, as almost any decision is related to the weather conditions. For this reason a special focus was given on finding low cost weather stations that can provide accurate data. The selected low cost weather station is being evaluated at an experiment ran at Municipality of Trikala, Greece, where the data of the low cost station was compared with the data of a high-end weather station used by the municipality. This high-end station was connected to the network of weather stations of National Observatory of Athens, which is the biggest network of weather stations in Greece, used for weather monitoring and forecasting. Both stations were installed in open places within municipality, their distance in straight line was about 400m and the measurements were taken every 10 minutes. **Figure 138** and **Figure 139** presents the comparison of the average temperature and the total rain respectively, recorded from the low cost and the high end weather stations for 30 days period.

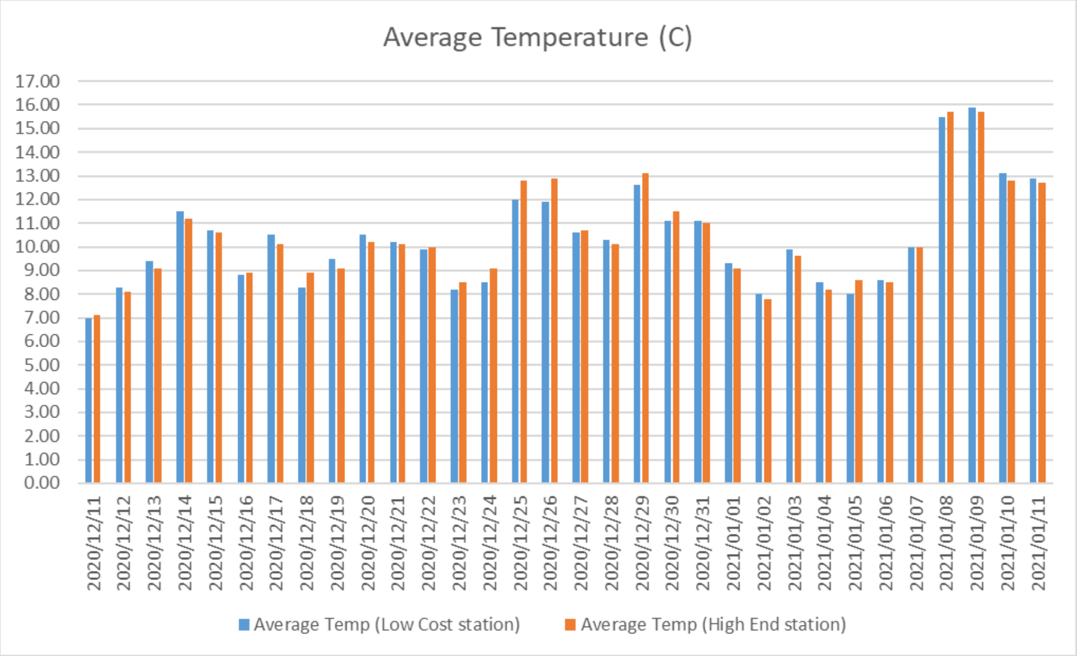


Figure 138: Comparison of the average temperatures recorded using the low-cost and high-end weather stations

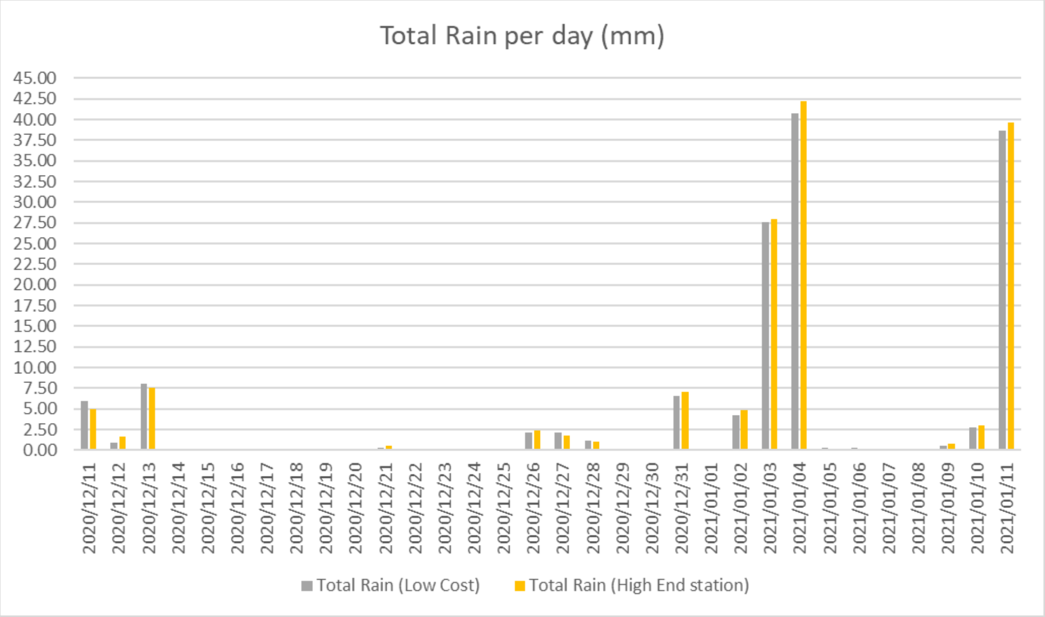


Figure 139: Comparison of the total rain recorded using the low-cost and high-end weather stations

The average temperatures recorded using the low-cost and high-end weather stations were 10.33 °C and 10.37 °C, respectively, while the total rain recorded was 142.50 mm for the low-cost weather station and 145.80 mm for the high-end weather station, proving the reliability of the measurements retrieved with the low-cost weather station. The proximity of the measurements of the low cost proposed system to the existing commercial weather station proves its reliability. Given that the cost of the IoT weather station presented is ¼ of the commercial ones gives the importance of the proposed design, and the capability to retrieve data of high quality using low cost sensors. As it proved from the above measurements, even low cost weather stations can provide an impressive accuracy of data, **which can help farmers and researchers to identify microclimate phenomena** that many times are not known even by the local communities.

At Mykonos Island, two sites for rainwater collection were created. The distance between them is only 600m in straight line with a small hill of 20m height between them (both sites were at the same attitude). During the construction phase of the sites it was manually noticed that when it was raining, the rainfall at the 1st site was higher than the 2nd site. For this reason low cost weather stations were installed at both sites. The measurements of the stations confirmed the manual observation. From the 23 times that rain events from 1/6/2020 to 9/1/2021, 14 times the rainfall at the 1st site was higher, the 5 of them was the same, and only 4 times the rain at the 1st site was lower (**Figure 140**). At the aforementioned period the total rain at the 1st site was 163.8mm while at the 2nd site 125.4mm which is around 30% bigger.

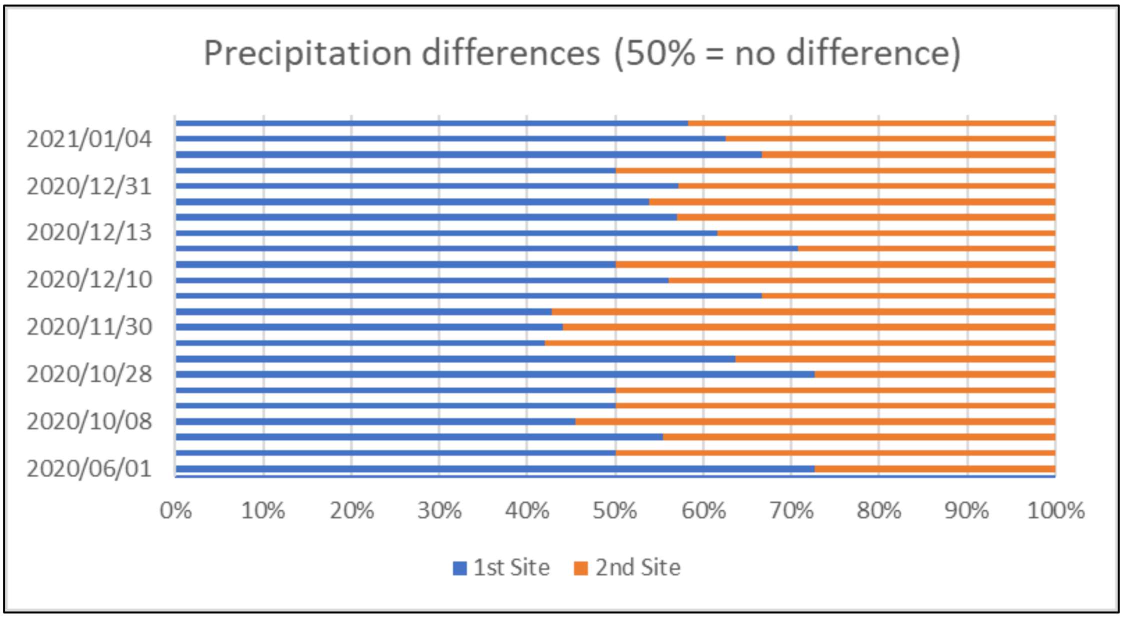


Figure 140: Precipitation differences

In another experiment that conducted in cooperation with Municipality of Trikala, 3 stations were placed in different areas of the municipality. The 1st station was placed at Trikala city center in an altitude of 114m, the second one at Prinos village 12.5km NW of Trikala city in an altitude of 153m and the 3rd one at Loggaki village 4.5km NE of Trikala city in an altitude of 100m. As their distance and their altitude difference were relativly small it was expected to retrieve similar measurements. The data taken proved that in most cases the various measurements followed the same pattern, with some of them to have relative small differences (e.g. Average Temperature – **Figure 141**), while others had huge differences (e.g. Maximum Wind Gust – **Figure 142** and precipitation – **Figure 143**).

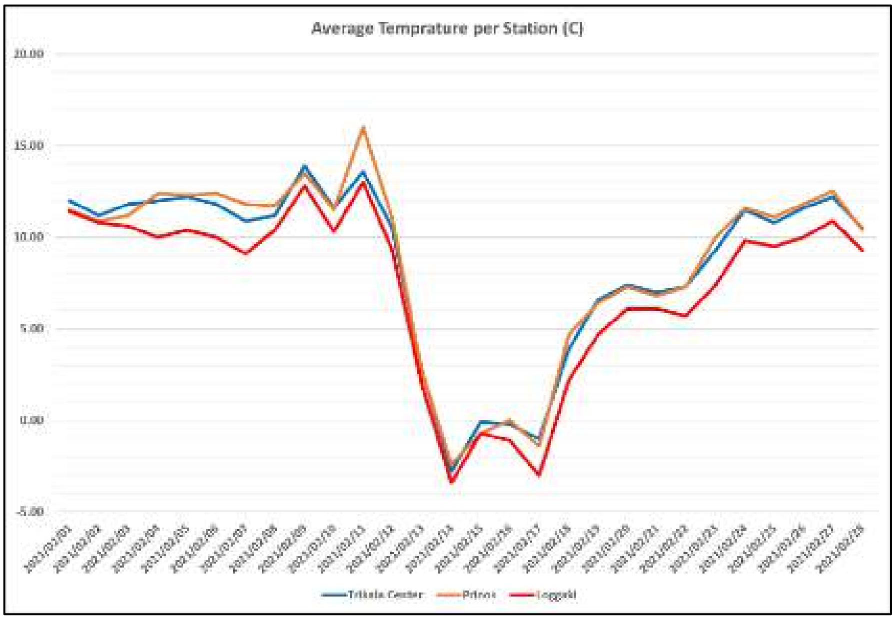


Figure 141: Temperature differences

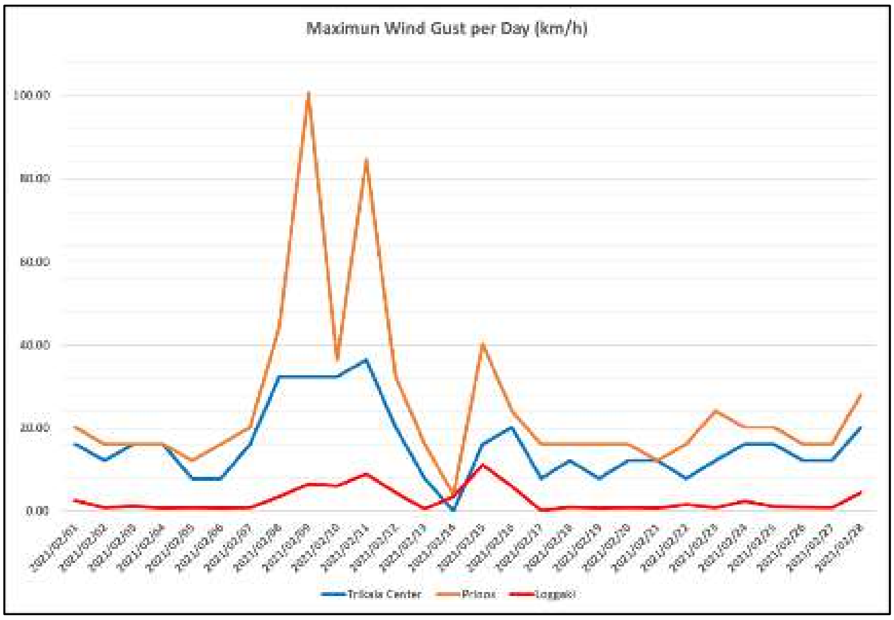


Figure 142: Maximum wind gust differences

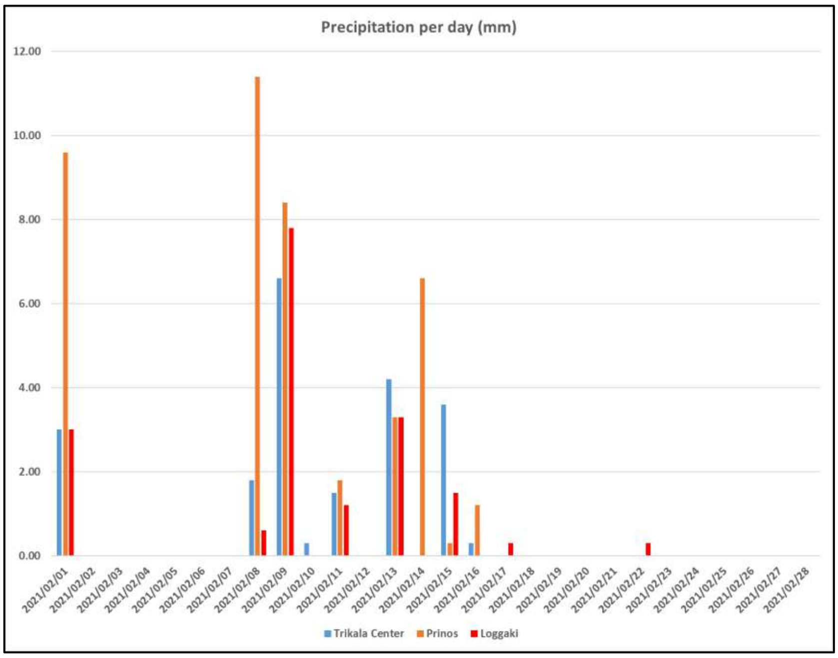


Figure 143: Precipitation differences

The results of these experiments, indicate the importance of measuring weather data in places even in small distance between the sites. This can be achieved only with weather station in or very near the field. That makes more necessary the usage of the FMMIS for retrieving field data. This would enable farmers to know better the real conditions of their fields and use them for improved decision making or improved control of practices like irrigation.

The accuracy of the data provided, in combination with the quite big amount of sensors supported both from the FMMIS and the IoT node as they follow an open architecture model, can be used for detailed monitoring of the agricultural environment and for drawing useful conclusions. **Figure 144** presents the monitoring of the evapotranspiration through soil and of solar radiation measurements, while **Figure 145** presents the correlation between precipitation and the soil moisture.

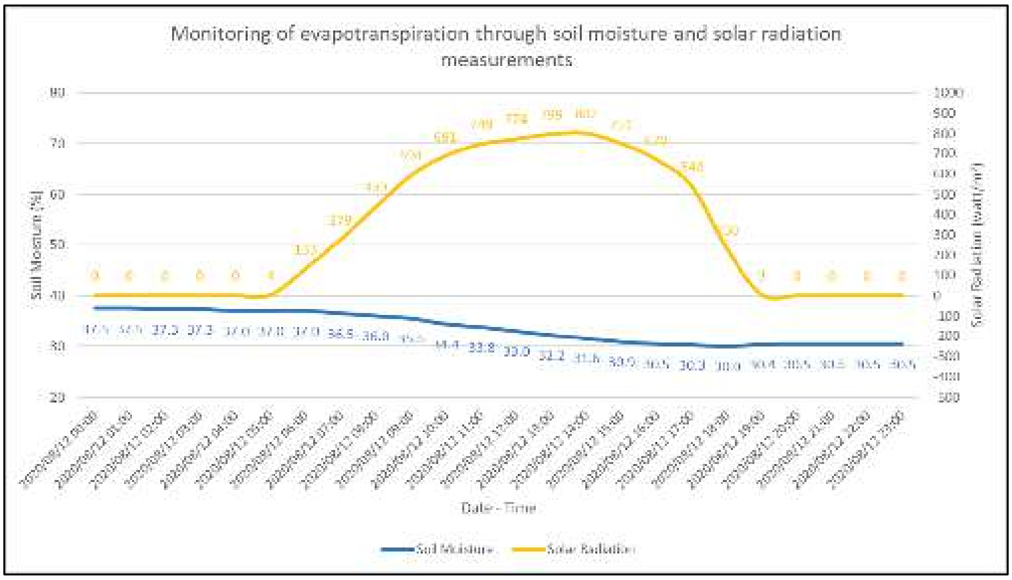


Figure 144: Monitoring of evapotranspiration

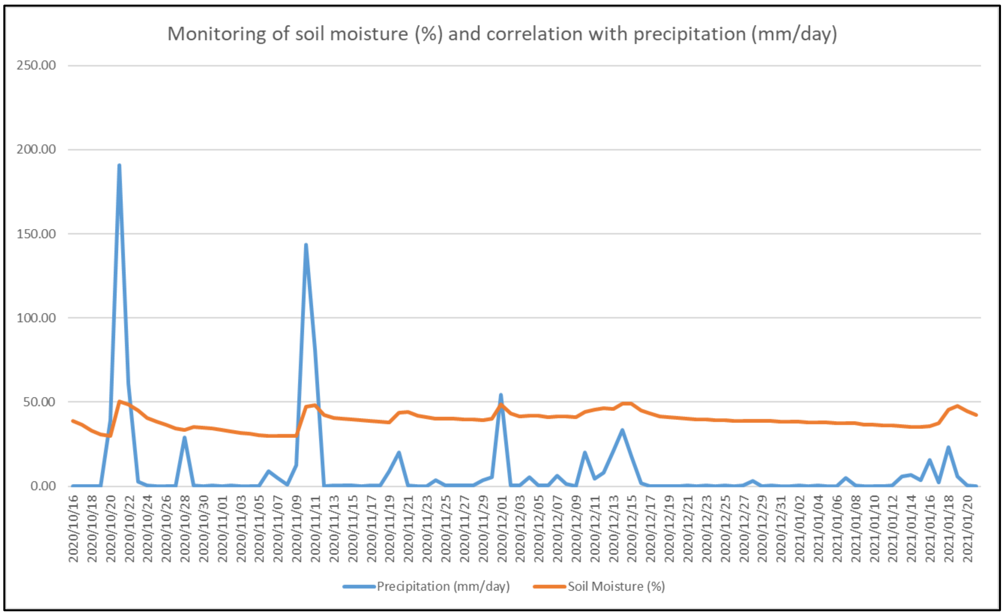


Figure 145: Monitoring of soil moisture and correlation with precipitation

3.4.3.1 Irrigation scheduling

The fact that the IoT node can be installed in any agricultural cropping system and activate different actuators, shapes the FMMIS ability to perform precise calculations of irrigation water needs and apply automated irrigation. To achieve this, the FAO56 Penman-Monteith model for computing crop water requirements was used. All the parameters for determining evapotranspiration were retrieved from sensors connected to the IoT node for monitoring the microclimate and the soil, while electrovalves were controlled from the node for enabling automated irrigation. The evapotranspiration value, in combination with the soil moisture measurements were used by FMMIS for calculating the irrigation water quantity needed.

Figure 146 and **Figure 147** presents the irrigation model results from the FMMMIS for determining the exact irrigation rate.

Acceptable irrigation conditions with recommended dosage: 153.4 m^3/ha

Evapotranspiration: 0.85 mm/day

Figure 146: Calculation of evapotranspiration and irrigation quantity

Figure 147: Evapotranspiration per day

For achieving these calculations the treatment table of the FMMIS database is storing the data using the fields presented in **Figure 148**.

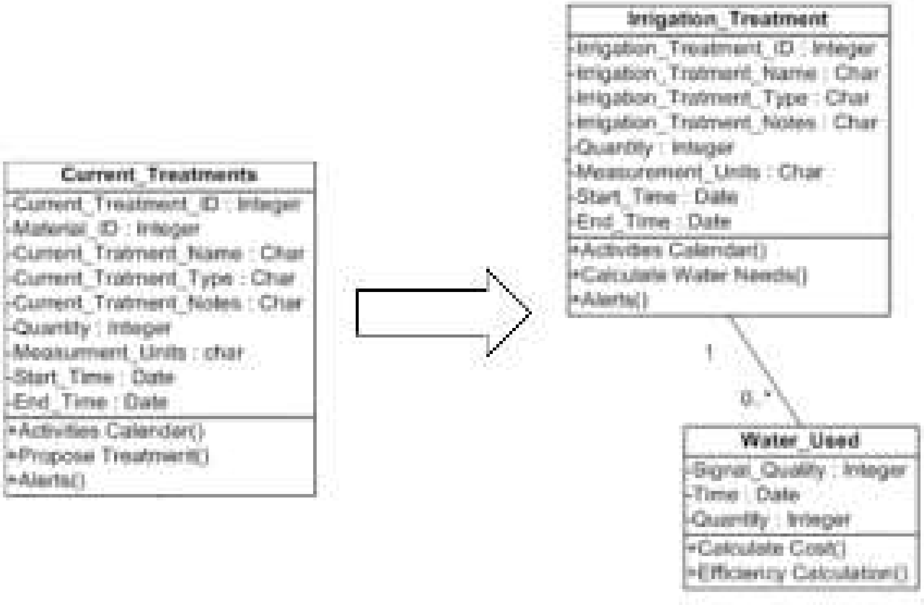


Figure 148: Irrigation treatment data

The fact that the IoT node can be installed in any agricultural cropping system and activate different actuators, shapes the FMMIS ability to perform precise calculations of irrigation water needs and apply automated irrigation. To achieve this, the FAO56 Penman-Monteith model for computing crop water requirements was used. All the parameters for determining evapotranspiration () were retrieved from sensors connected to the IoT node for monitoring the microclimate and the soil, while electrovalves were controlled

For testing the irrigation scheduling capabilities of the FMMIS, a greenhouse was split into four plots, in which different tropical crops, such as bananas and pineapples, were cultivated. The irrigation of each plot was achieved using a drip irrigation system, and the irrigation schedule was fully automated using the developed IoT node (**Figure 149**).

Figure 149: IoT nodes for automating the irrigation in the greenhouse

Figure 150 presents the average soil moisture per day and the days in which irrigation was applied (1 = Irrigation, 0 = No irrigation) from 15 October 2021 to 12 November 2021. From the figure, it is clear that the FMMIS was capable of efficiently irrigating the crops without stressing them, keeping soil moisture between 30 and 38%. Moreover, as evapotranspiration reduces during the winter, it clearly seems that the frequency of irrigation is lower in November compared to that in October.

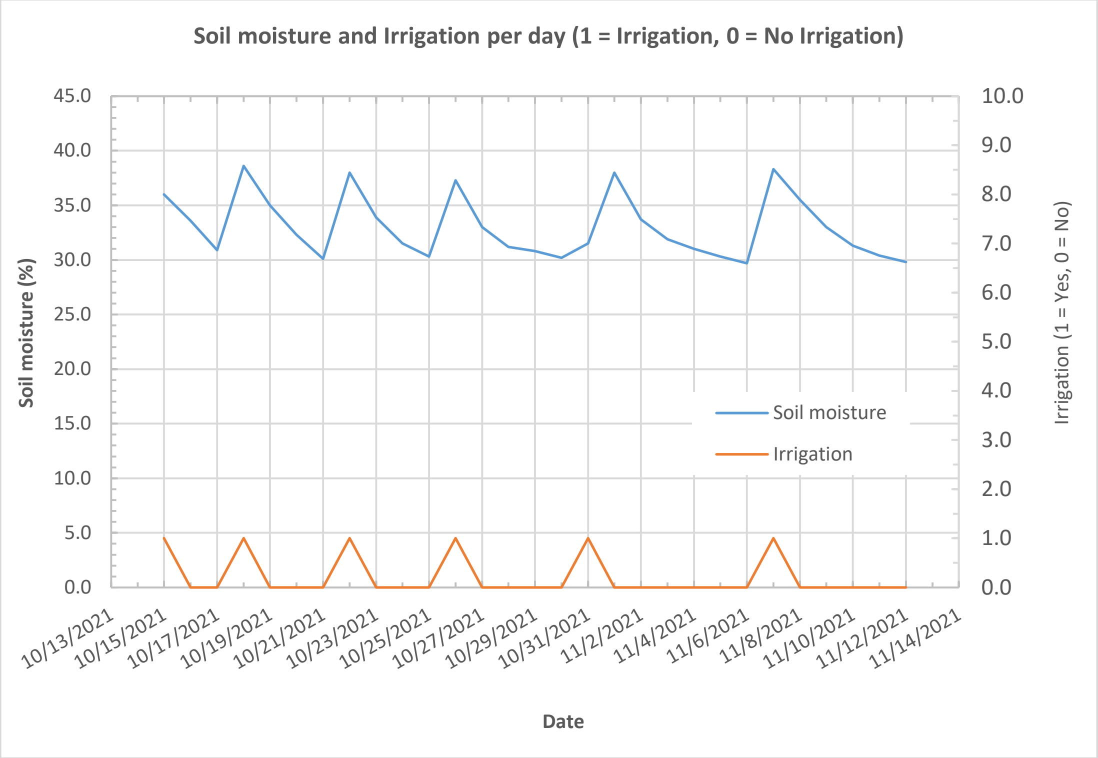


Figure 150: Automated irrigation using FMMIS

For comparing the reduction that can be achieved two different treatments were applied. The one was totally automated, using the FMMIS, while the second one was conventional irrigation that was performed by an experienced agronomist. The average consumption was 1.6m^3 per day for the conventional irrigation, while the consumption using automated irrigation was 0.9m^3 per day, which indicates a 43.75% decrease. This difference was a result of the fewer amount of irrigation treatments (approximately 10%), and the smaller quantity irrigated by the automated system per treatment, compared to conventional irrigation in which the Field Capacity was over excess.

The FMMIS was also tested in open crops. **Figure 151** presents the average soil moisture per day, in a clay loam field cultivated with onions that was automatically irrigated by the system.

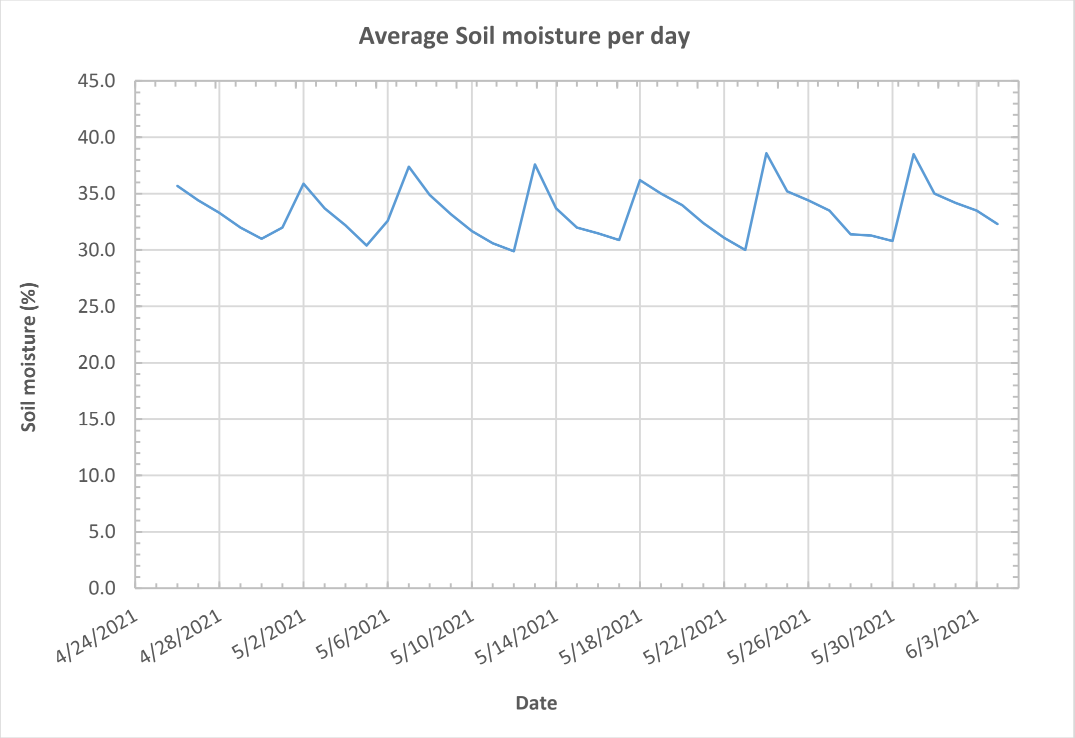


Figure 151: Average soil moisture per day

Agriculture is the largest consumer of water in the Mediterranean, reaching over 72% of total consumption. The problem of water scarcity occurs both on the island and on the mainland. For example in Thessaly, the lack of water has led to the use of boreholes >400 m deep. This implies a great waste of energy and an increase in the cost of irrigation, while it also has an impact on water quality, as problems are identified due to the infiltration of seawater into the underground aquifer.

In addition, over-irrigation of crops by producers increases the pressure on water sources and contributes to the depletion of fresh water reserves. However, the large amounts of irrigation are not utilized by the plants, since as has been observed losses exceed 50%. Combining all of the above with the fact that, according to the World Resources Institute, Greece, along with other countries in the Mediterranean, are at risk of experiencing a severe water shortage problem by 2040, it is understood that the need to find solutions for the sustainable management of water resources is imperative, in order to ensure environmental and economic development.

3.4.3.2 Water quality assessment

For the above reasons the FMMIS in combination with the IoT node, were tested in water circular solutions, for proving system's ability on contributing at minimizing the negative effects of agriculture in water resources. As in most water circular solutions, the water is stored into various constructions, measuring its quantity and quality is of great importance.

The water quality sensors were tested and evaluated at a pilot site at Agios Fokas, Tinos, Greece, by comparing their measurements with industrial type sensors that were installed in parallel in closed tanks used for water storing. Both low-cost and industrial sensors were calibrated before their installation. The measurement rate was 1 h for the low-cost sensors and 15 min for the industrial sensors. To compare their results, the average daily values of each sensor were calculated. For pH measurements, the maximum difference recorded between the low-cost and the industrial sensor was 0.22 with a mean difference at 0.08 and $R^2 = 0.8392$ (**Figure 152** and **Figure 153**), with the low-cost sensor having an accuracy of ±0.1 at 25 °C and the industrial one ±0.05 (from 0 °C to 60 °C). For water temperature measurements, the maximum difference recorded was 1.78 °C with a mean difference of 0.75 °C and $R^2 = 0.9914$ (**Figure 154** and **Figure 155**), with both sensors having an accuracy of ±0.5 °C (low cost: from −10 °C to +85 °C; industrial: from 0 °C to 60 °C). The average values per day and their differences are shown in **Table 11.**

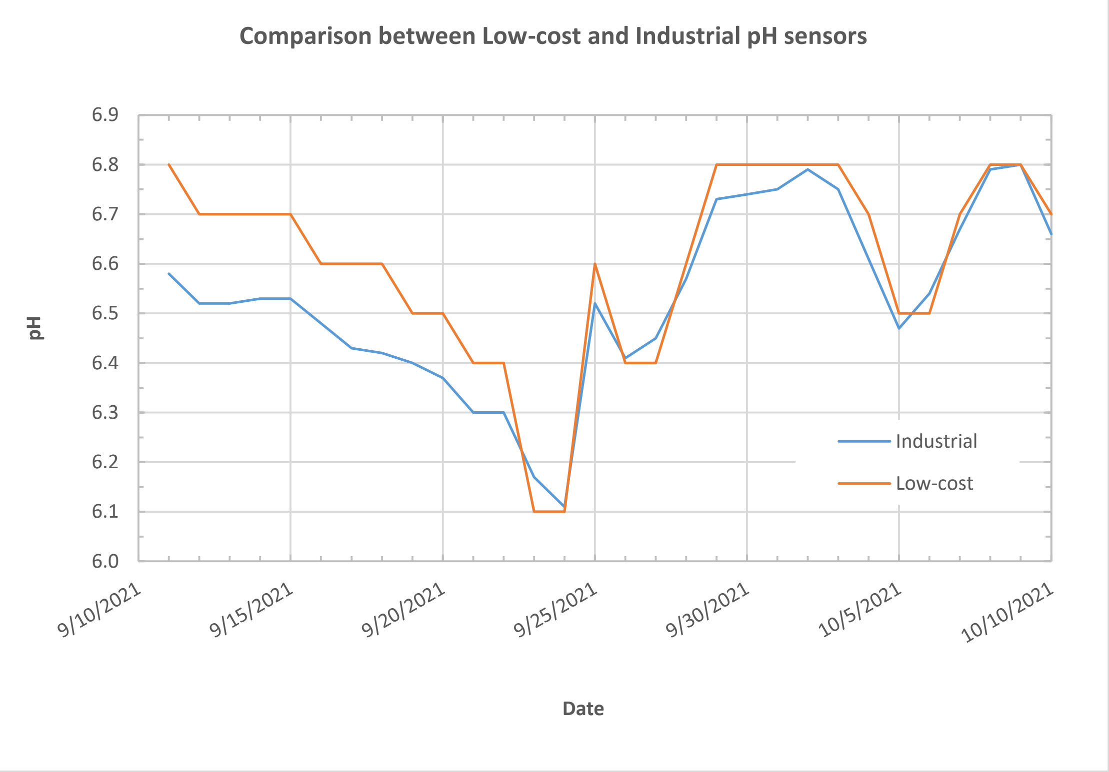


Figure 152: Comparison of industrial and low-cost pH sensors' measurements

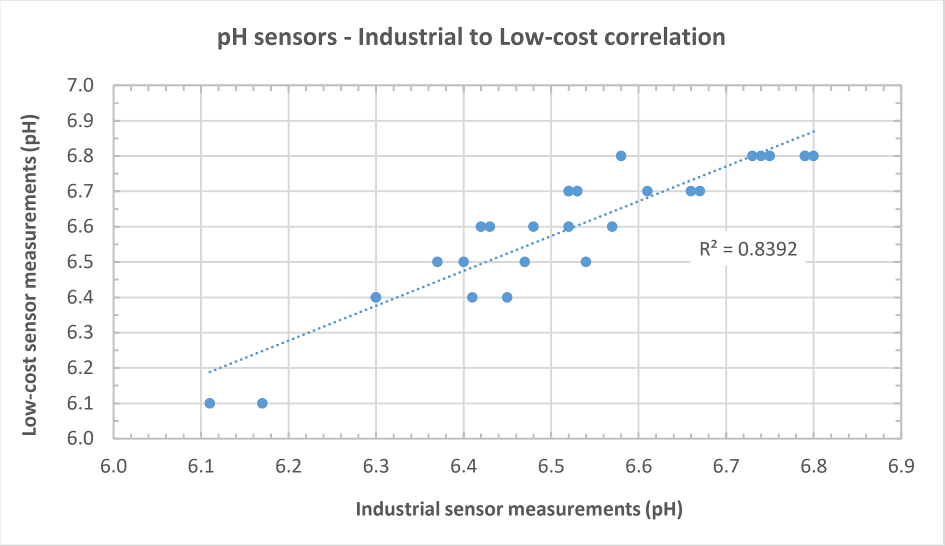


Figure 153: Correlation of industrial and low-cost pH sensors' measurements

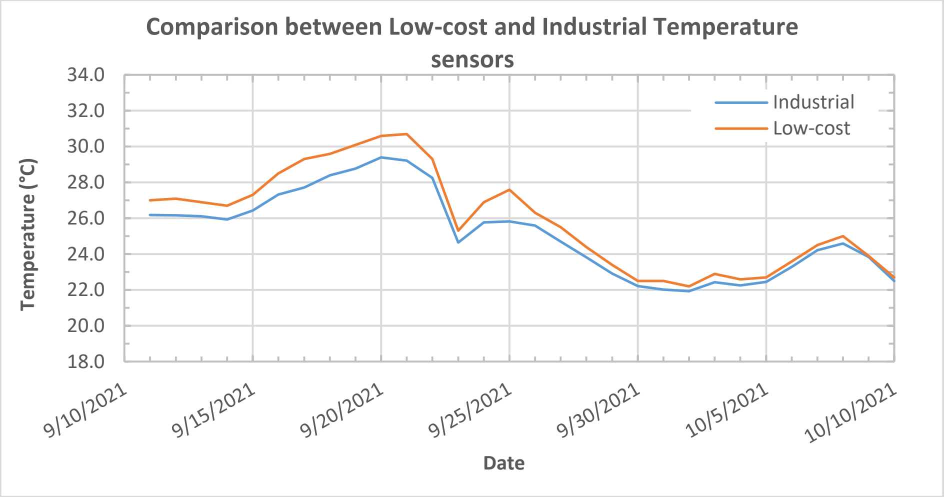


Figure 154: Comparison of industrial and low-cost temperature sensors' measurements

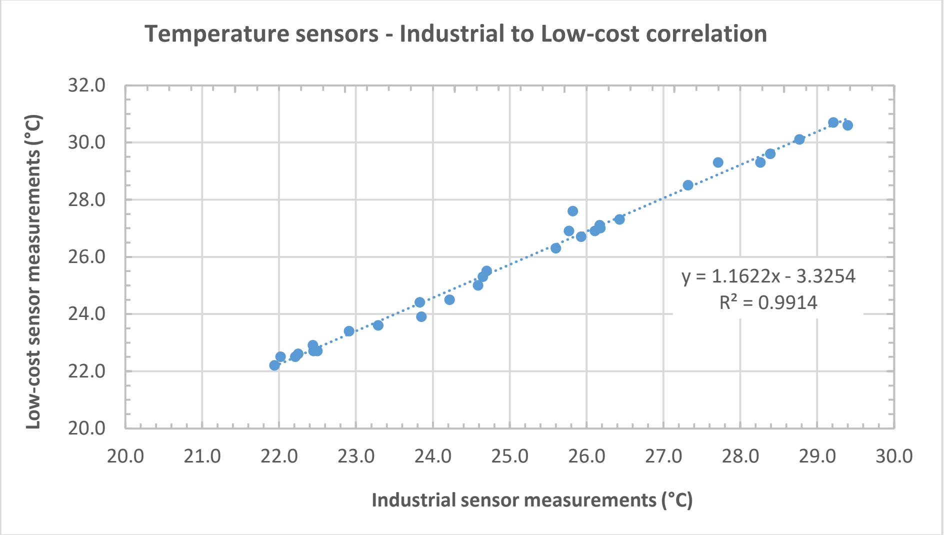


Figure 155: Correlation of industrial and low-cost temperature sensors' measurements

Table 11: Comparison of the measurements of the low-cost and industrial sensors. The different letters accompanying daily means and monthly average values of each distinct measurement type (pH and temperature) for each set of the industrial and low-cost sensors indicate a significant difference between the measurements, based on a Fisher's least significance difference (LSD) test ($p < 0.05$).

Date	pH Industrial		pH Low Cost		pH Difference	Temperature Industrial		Temperature Low Cost		Temperature Difference
10 September 2021	6.61	a	6.80	b	0.19	25.63	a	26.20	a	0.57
11 September 2021	6.58	a	6.80	b	0.22	26.18	a	27.00	a	0.82
12 September 2021	6.52	a	6.70	b	0.18	26.17	a	27.10	b	0.93
13 September 2021	6.52	a	6.70	b	0.18	26.11	a	26.90	a	0.79
14 September 2021	6.53	a	6.70	b	0.17	25.93	a	26.70	a	0.77
15 September 2021	6.53	a	6.70	b	0.17	26.43	a	27.30	b	0.87
16 September 2021	6.48	a	6.60	b	0.12	27.32	a	28.50	b	1.18
17 September 2021	6.43	a	6.60	b	0.17	27.71	a	29.30	b	1.59
18 September 2021	6.42	a	6.60	b	0.18	28.39	a	29.60	b	1.21
19 September 2021	6.40	a	6.50	b	0.10	28.77	a	30.10	b	1.33
20 September 2021	6.37	a	6.50	b	0.13	29.40	a	30.60	b	1.20
21 September 2021	6.30	a	6.40	b	0.10	29.21	a	30.70	b	1.49
22 September 2021	6.30	a	6.40	b	0.10	28.26	a	29.30	b	1.04
23 September 2021	6.17	a	6.10	a	0.07	24.65	a	25.30	a	0.65
24 September 2021	6.11	a	6.10	a	0.01	25.77	a	26.90	b	1.13
25 September 2021	6.52	a	6.60	a	0.08	25.82	a	27.60	b	1.78
26 September 2021	6.41	a	6.40	a	0.01	25.60	a	26.30	a	0.70
27 September 2021	6.45	a	6.40	a	0.05	24.70	a	25.50	a	0.80
28 September 2021	6.57	a	6.60	a	0.03	23.83	a	24.40	a	0.57
29 September 2021	6.73	a	6.80	a	0.07	22.91	a	23.40	a	0.49
30 September 2021	6.74	a	6.80	a	0.06	22.21	a	22.50	a	0.29
1 October 2021	6.75	a	6.80	a	0.05	22.02	a	22.50	a	0.48
2 October 2021	6.79	a	6.80	a	0.01	21.94	a	22.20	a	0.26
3 October 2021	6.75	a	6.80	a	0.05	22.44	a	22.90	a	0.46
4 October 2021	6.61	a	6.70	b	0.09	22.25	a	22.60	a	0.35
5 October 2021	6.47	a	6.50	a	0.03	22.45	a	22.70	a	0.25
6 October 2021	6.54	a	6.50	a	0.04	23.29	a	23.60	a	0.31
7 October 2021	6.67	a	6.70	a	0.03	24.22	a	24.50	a	0.28
8 October 2021	6.79	a	6.80	a	0.01	24.59	a	25.00	a	0.41
9 October 2021	6.80	a	6.80	a	0.00	23.85	a	23.90	a	0.05
10 October 2021	6.66	a	6.70	a	0.04	22.50	a	22.70	a	0.20
Average	6.53	a	6.61	a	0.08	25.18	a	25.93	a	0.75

The evaluation of the FMMIS capability to measure stored water and to use it efficiently for irrigation scheduling was done in a pilot site at Mykonos Island, in which two open top tanks were constructed for storing rainwater from a sub-surface rainwater collection system (**Figure 156:** (a) Open top water tanks; (b) Sub-surface rainwater collection system).

(a) (b)

Figure 156: (a) Open top water tanks; (b) Sub-surface rainwater collection system

The collected water was used for the irrigation of a 0.4 ha oregano field using the rainwater stored into the open tanks. One small pressure booster pump in combination with electrovalves controlled by the IoT nodes was placed for controlling the water flow between the two tanks and for enabling irrigation (**Figure 157**), while to determine the level of stored water into the tanks, ultrasonic sensors were used (**Figure 158**).

Figure 157: Electrovalve for controlling the water flow

Figure 158: Level sensor installed in one of the tanks.

Depending on the water quantity monitored in each tank, the appropriate electrovalve is opened to irrigate the crop using the water stored in one of the two tanks. **Figure 159** projects the sum of the water quantity stored in both tanks during the period from 22 July 2021 to 23 September 2021. The small differences that were observed during the monitoring (±0.5 m³) come from the effect of sunlight on the accuracy of the level measured by the sensors.

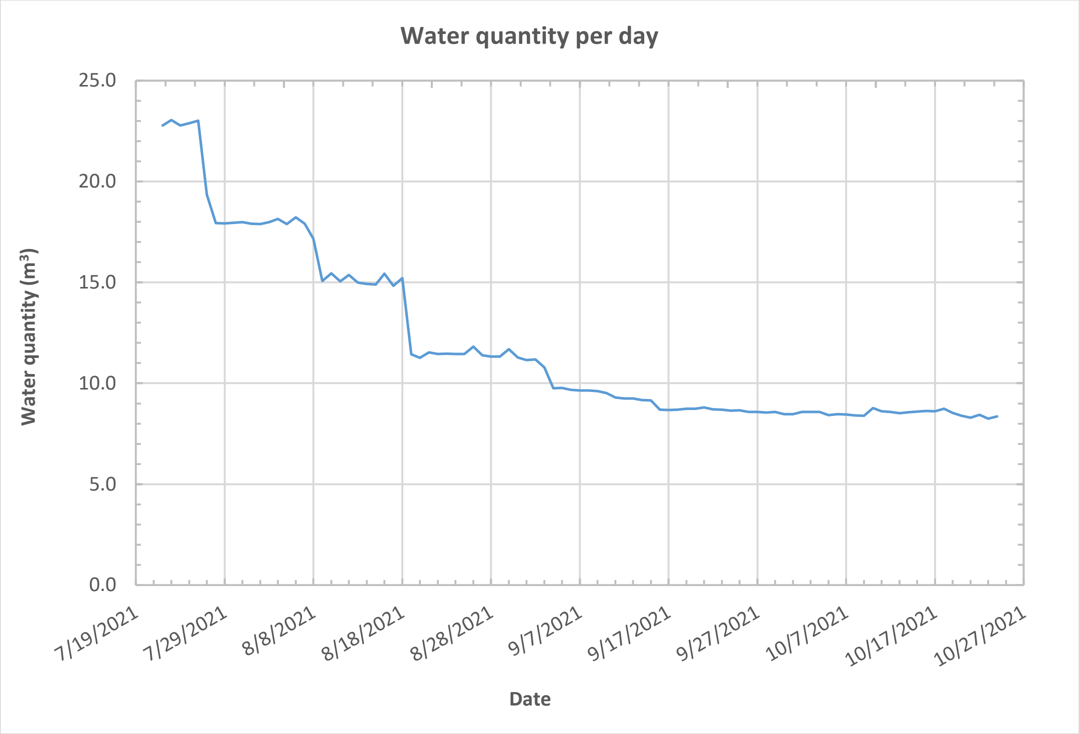


Figure 159: Water quantity monitoring

3.4.4 Discussion and conclusions

The findings in this research indicate that low-cost technologies and standards can be used for developing low-cost, highly accurate, and easy-to-use IoT systems that can be embedded into a FMMIS for enabling agricultural operations as irrigation scheduling and water management.

As the node was exclusively based on the Arduino architecture and components, its hardware cost was very low, making it affordable to any farmer. The node was developed as a pure IoT device supporting cellular network technology protocols, making it capable of working in any area in which a cellular network is available. Furthermore, as the price of sensors is constantly dropping, farmers can purchase sensors of high accuracy that can almost provide a perfect coefficient of determination ($R^2 = 0.9914$) at a very low price, permitting the fast depreciation of the investment for the system. As these sensors can provide data of high quality, their use can help farmers in decision making, by minimizing the inputs' cost and increasing their production. Likewise, low-cost actuators can be applied for automating and for remote controlling water management, increasing the usability of the system.

The sensors, after small modifications mostly related to making them waterproof, were proved to be sufficiently accurate and working properly. FMMIS using inputs from the IoT node was able to provide a variety of different type of measurements, including weather data, water quantity data, water quality data, and soil data. By computing crop water requirements using the FMMIS, it was possible to automate irrigation scheduling providing the optimal water quantity, while simultaneously minimizing its consumption.

The IoT node was developed as a “plug and play” device and pushing its start button is the only action needed for making the node fully functional. By adopting this simplified user experience, there is no need of any special knowledge or training for installing and configuring it, contributing on removing the demographic traits of the farmers barriers, which affect the adoption of new technologies.

IoT node’s small size, its durability, and its extensive energy autonomy make it suitable for a lot of cases, providing its effectiveness and usability. The node has proved to be extremely reliable, as to date there have been no hardware fails. Its development with open source Arduino technologies makes it modular, flexible, and upgradable to support more sensors and actuators than the existing ones, finally suggesting its capability for application in combination with the FMMIS in a vast number of agricultural operations in the future.

Originally, the IoT system was developed for monitoring and controlling water to enable smart irrigation in open fields. As a result of its characteristics (very small size, energy autonomy, automation capabilities, high accuracy, support of different types of sensors, IP67 protection, and its low price), the holistic system of the FMMIS and the IoT node was already tested in various environments as forestry (monitoring of environmental parameters in forests), large water infrastructures (monitoring of water quantities), meteorology (for monitoring the weather), and for smart cities with very promising initial results.

4 Discussion and conclusions

As the global population is constantly increasing and the cultivated areas are decreasing, new IR4 technologies will become a necessity, as the only sustainable way for increasing agricultural output. Under this aspect, this thesis investigated the development of an innovative Farm Machinery Management Information System (FMMIS) and its usage in three different use cases, for showcasing its operability and its positive impact on the daily agricultural management and to the agricultural domain in general.

For achieving it, a first step was the reviewing of commercial FMIS applications current situation and future perspectives for incorporating their functionalities into the FMMIS. The analysis included 141 FMIS packages focused on crop production in open-fields. These tend to focus on solving daily farm tasks and aim to generate income for the farmers through better resource management and field operations planning. Key research representing areas for further development and improvement for currently applications include improvements in technology, adaptation motives, hindrances, specific new functionalities and greater emphasis on software design governed by usability and human–computer interaction. In this respect, the diffusion of information management as business innovation in the farming community could benefit from the comprehensive research developed in the last decades on the adoption of ICT and e-commerce among both consumers and small businesses. This study has provided a stepping stone for further development of FMIS. In the past, a key issue was the adoption of farm computers, but this has advanced to include more sophisticated information and communication solutions. This is necessary to ensure the required advancement from the basic use of farm data recording and processing systems to the adoption of a sophisticated FMIS that truly supports the farm manager's decision making process. Importantly, the results identified new functionalities like distributed management systems that must in the near future be implemented in FMIS or FMMIS if the farming community is to fully embrace possibilities and the benefits of the new available technologies.

Following this, and as the main functionalities of the current FMISs were identified and future improvements were suggested, the basic outline and structure for a Farm Machinery Management Information System was designed and proposed, able to fully incorporate the new trends of on-the-go sensors and ISOBUS data transfer protocols and striving toward full automation of all tasks needed in the management and the operation of a farm. This system is compatible with the latest generation of tractors and agricultural implements, and with the future autonomous vehicles applicable for agricultural operation. This study has shown the benefits of participatory research, including farm managers and tractor drivers, using a dedicated system analysis methodology, the soft systems methodology (SSM) as a preliminary step to the actual design of a novel farm machinery management information system. It has shown that the use of SSM allows a fundamental analysis, incorporating the identification of required changes. The results included three rich pictures and three conceptual models which in the case of the current system depict the conventional manned tractor and in the case of future scenarios envision a small field robot and a conventional autonomous tractor. The designs entail complete supervision, control and automated management and operation of agricultural machinery systems. The depicted systems have common characteristics and the differences concern type of technology and subsequent capabilities. The final FMMIS models comprise complete data collection and processing of all parameters of a farm (crops quality and quantity, agricultural equipment management, inventory management, economic analysis, best practice, etc.) using all available instruments and subsystems that can be used on a farm. These capabilities are facilitated and supported by advanced and specialized functions and features such as system communication with government agencies, research centers, universities, manufacturers, agriculturists in order to automate additional functions of a farm such as the automation of subsidies, remotely crop observation by experts, and the remote inspection of vehicles operation parameters and diagnosis by the manufacturers of agricultural equipment. That led to the definition of the final FMMIS architecture and the 16 different functionalities (modules) that a FMMIS must have.

A last step before the development of the FMMIS was the analysis of its adoption from agricultural community. For achieving this, a qualitative analysis was conducted in order to understand the attitude of farmers towards ICT innovations and evaluate the adoption of new software solutions for farm information management. The results used for developing the FMMIS in such a way to positively response on all the major factors that affecting farmer decision for new agricultural technologies adoption. For this reason, the FMMIS developed having as main principles its easiness to use, its reliability and accuracy, its usability and effectiveness, and most importantly its potential low price, as the most important factor that affecting the adoption of new technologies in small farms, is their cost.

The final FMMIS was developed as a web-based application, using C# and has a responsive design, which is automatically adjusts to different screen sizes, allowing to be easily viewable and workable at any device (computer, mobile phone etc.) or screen resolution. It consists of all major visualization components needed for projecting and analyzing data, as tables, charts information tabs and gauges. Moreover, it was enriched with a powerful GIS module which provides all the necessary tools and functionalities needed for analyzing spatial data that can be created during agricultural operations. In addition, it contains wizards and multiple customization options for increasing its user-friendliness, it has alerting and notification capabilities for quickly distributing important messages to the farmer, it supports decision making by running various algorithms (e.g. irrigation scheduling), it enables remote controlling of Unnamed vehicles and agricultural equipment (e.g. electrovalves, pumps), and it can automate agricultural operations (e.g. irrigation, unmanned vehicles route planning etc.). For supporting the aforementioned functionalities and for providing extreme interoperability with systems, tools, and services that were not predicted or existed during its implementation, a key feature of FMMIS is the ability to be compatible with data coming from sources that were not anticipated in the original design, FMMIS database stores the data of every different entity in just one table for each entity and uses the technology of the rotating tables by executing the necessary queries. In this way, the final FMMIS is able to separate and to analyze data from sources unforeseen in the initial design.

The FMMIS was tested and validated in three different use cases. The first case, was the spatial analysis of tractor–implement draft forces for reduced fuel consumption and increased efficiency. The results showed that the analysis of tillage implement forces are of great importance as they can indicate to the tractor driver the efficiency of the tillage, and to be used for minimizing the fuels consumption during tillage operations. Using the proposed system which consisted of a dynamometer and a hardware with the capability to measure fuel consumption through ECU (for modern tractors) or flowmeters (to older tractors), a fuel reduction can be achieved, and the tillage quality can be optimized, as it can inform tractor driver about the tillage depth alteration as well as for the correction on link and level adjustment.

According to studies, conventional tillage has an average fuel consumption of 52 l/ha[209]. Using the proposed system a reduction of fuel consumption up to 50% can be achieved, leading to a reduction of fuel consumption up to 26 l/ha. Table below (Table 1) lists information on agricultural land per farm in Europe, America and the rest of the world as well as the fuel prices. For America and the rest of the world, the necessary currency conversions of the prices were made in €/liter to make comparisons possible. The price for the rest of the world was used as an indication, as the price differences between countries and are likely to change in an unpredictable manner and certainly at a faster rate.

Table 12: Farm size and average fuel cost reduction

	Europe	USA	Rest of World
Average farm size	17 ha	180 ha	5,5 ha[210]
Fuel cost	1.71 € / l [211]	4.62 $ / gallon [212] = 1.10 € / l	1.33 $ / l [213] = 1.22 € / l
Average cost per hectare	88.92 € / ha	57.2 € / ha	63.44 € / ha
Average fuel cost per farm per year	1511.64 €	10,296 €	348.92 €
Average fuel cost reduction (50% percent fuel consumption reduction)	**755,82 €**	**5.148 €**	**422,13 €**

As it is obvious from the table, the bigger the farm, the biggest reduction of fuel costs is achieved. With an estimated price of 4000 Euros for purchasing such a system (if it was commercial), the system has a payback time of less than a year for an average American farm, and 5 years for the average European farm. With the fuel prices increasing constantly, these results are expected to be reduced even more, providing to farmers a solution that can reduce the usage of fossil fuels, contributing at farm sustainability by making it more profitable in a small period of time.

A second FMMIS use case, was the development of an Unmanned Ground Vehicle (UGV) for agricultural operations at orchards and vineyards. The aim of this use case was to showcase the capabilities of new ICT technologies on automating agricultural operations using unmanned vehicles. For achieving it, the methodology, the operation principles, the safety measures and the necessity of simulation of the route planning was presented.

The robot was developed with setting the aim to create a low cost robot with the capability to efficiently move inside the agricultural harsh environment. For this reason, an ATV was selected, and was modified for enabling its autonomous operation. Its operability and capabilities were proved in tests that were held both in simulated and real environment. The cost of developing the prototype, was around 10,000 Euros, which can be reduced in case of commercialization as a result of the economy of scale. Developing low cost robots that can automate agricultural operations will arise a new era at agricultural management, where most of agricultural operations will be automated, and everything will be controlled and inspected from farmers and farm managers from everywhere via the World Wide Web.

The last use case, was the design and development of a low cost IoT node for Precision Agriculture. It was mostly focused on precision irrigation and water management, as in Greece one of the most important problem is the water scarcity. To this extend, in the Mediterranean region, significant contrasts are presented in terms of the distribution of population and water resources. Characteristically, the intense ones that occurred between 1990 and 2005 in the Mediterranean region created serious shortages in the dry amount of water even in the industrialized countries of the Northern Mediterranean, something that has not returned to date and is not predicted. At the same time, in the last 50 years, the great demand for water has doubled as a result of demographic pressure and the development of water-intensive activities such as tourism and manufacturing. All of the above mentioned elements support the fact that it is imperative to take decisions and actions, especially in the agricultural sector that consumes the largest percentage of available water, to re-evaluate the ways of managing water resources, to turn attention to the circular economy and the reuse of resources but also in raising awareness for better water management in the agricultural sector.

For making the IoT system affordable even from small farms, which is the majority of agricultural holdings in Greece, the system was developed using the full aspects of new IR4 technologies. During its validation, it was proved that despite its low cost, it can provide high accuracy, durability and efficiency and can minimize the water consumption 30% compared to conventional practices. With an estimated price of 1,000 Euros for purchasing such a system which enabling irrigation scheduling, the system has a very fast payback period for the farmers.

To calculate the payback period for irrigated crops in Greece, the money savings that farmers would have by using it was estimated (**Table 3** and **Table 4**). It was assumed that the average cultivated area in Greece is 7 hectares[214], the irrigation cost was set from 0.01€/m^3 to 0.10 €/m^3 for farms retrieving water from water utilities[215], and from 0.15 up to a maximum 0.25 – 0.40€/m^3 for farms that are using water from drills[216], while the most common crops that are cultivated in Greece are consuming: Cotton, Tomatoes (5,500 m^3 / ha), maize (6,000 m^3 / ha), trees (7,500 m^3 / ha) and vegetables (8,000 m^3 / ha). The payback period is defined as the time it takes for the buyer to obtain a benefit equal to the initial investment he has made.

Table 13: Average saving per average farm (water utilities)

Average cultivated area	7 ha	
Irrigation cost	0.06 €/m^3	
Average water consumption for irrigation	Cotton, Tomatoes, Maize	Trees, Vegetables
	5,750 m^3 / ha	7,750 m^3 / ha
Irrigation cost for given water consumption	2,415 €	3,255 €
Average savings per cultivation period (with 30% reduction in water consumption)	**724,5 €**	**976.5 €**
Payback time	**1.38 years**	**1.02 years**

Average cultivated area	7 ha			
Irrigation cost	Low Cost: 0.01 €/m^3		High Cost: 0.10 €/m^3	
Average water consumption for irrigation	Cotton, Tomatoes, Maize	Trees, Vegetables	Cotton, Tomatoes, Maize	Trees, Vegetables
	5,750 m^3 / ha	7,750 m^3 / ha	5,750 m^3 / ha	7,750 m^3 / ha
Irrigation cost for given water consumption	402 €	543 €	4,025 €	5,425 €
Average savings per cultivation period (with 30% reduction in water consumption)	**121 €**	**163 €**	**1,208 €**	**1,627 €**
Payback time	**8.26 years**	**6.13 years**	**0.82 years**	**0.61 years**

Table 14: Average saving per average farm (water from drills)

Average cultivated area	7 ha			
Irrigation cost	Low Cost: 0.15 €/m^3		High Cost: 0.25 €/m^3	
Average water consumption for irrigation	Cotton, Tomatoes, Maize	Trees, Vegetables	Cotton, Tomatoes, Maize	Trees, Vegetables
	5,750 m^3 / ha	7,750 m^3 / ha	5,750 m^3 / ha	7,750 m^3 / ha
Irrigation cost for given water consumption	6,037 €	8,137 €	10,062 €	13,562 €
Average savings per cultivation period (with 30% reduction in water consumption)	**1,811 €**	**2,411 €**	**3,018 €**	**4,068 €**
Payback time	**0.55 years**	**0.41 years**	**0.33 years**	**0.25 years**

Respectively, **Table 15** presents the payback period for water price from 0.01 €/m^3 to 0.40 €/m^3 for the average Greek farm.

Table 15: Payback period for different water prices.

Water cost (€/m^3)	**Average savings per cultivation period (Cotton, Tomatoes, Maize)**	**Average savings per cultivation period (Trees, Vegetables)**	**Payback time (years)**	**Payback time (years)**
0.01	121	163	8.28	6.14
0.02	242	326	4.14	3.07
0.03	362	488	2.76	2.05
0.04	483	651	2.07	1.54
0.05	604	814	1.66	1.23
0.06	725	977	1.38	1.02
0.07	845	1139	1.18	0.88
0.08	966	1302	1.04	0.77
0.09	1087	1465	0.92	0.68
0.10	1208	1628	0.83	0.61
0.11	1328	1790	0.75	0.56
0.12	1449	1953	0.69	0.51
0.13	1570	2116	0.64	0.47
0.14	1691	2279	0.59	0.44
0.15	1811	2441	0.55	0.41
0.16	1932	2604	0.52	0.38
0.17	2053	2767	0.49	0.36
0.18	2174	2930	0.46	0.34
0.19	2294	3092	0.44	0.32
0.20	2415	3255	0.41	0.31
0.21	2536	3418	0.39	0.29
0.22	2657	3581	0.38	0.28
0.23	2777	3743	0.36	0.27
0.24	2898	3906	0.35	0.26
0.25	3019	4069	0.33	0.25
0.26	3140	4232	0.32	0.24
0.27	3260	4394	0.31	0.23
0.28	3381	4557	0.30	0.22
0.29	3502	4720	0.29	0.21
0.30	3623	4883	0.28	0.20
0.31	3743	5045	0.27	0.20
0.32	3864	5208	0.26	0.19
0.33	3985	5371	0.25	0.19
0.34	4106	5534	0.24	0.18
0.35	4226	5696	0.24	0.18
0.36	4347	5859	0.23	0.17
0.37	4468	6022	0.22	0.17
0.38	4589	6185	0.22	0.16
0.39	4709	6347	0.21	0.16
0.40	4830	6510	0.21	0.15

It is clear that the system has a very small payback period which is approximately 1 year for water prices at from 0.06 €/m^3 to 0.08 €/m^3 depending the crop. For higher water cost, the prices are reduced even more. It is important to mention that not only irrigation water is saved, but also the yield is increased and the cost of transportation to the farm for starting/ending the irrigation is reduced minimizing even further the payback time. The aforementioned results prove that the FMMIS in combination with low cost but accurate IoT equipment can have a major contribution in reducing the cost of the inputs, and to minimize the negative effects of agriculture to the environment, as the system controls and reduces water overconsumption, at a price that is affordable for almost any farm as the payback time is very small.

From these three cases, it was proved that the developed FMMIS can have countless positive repercussions in the agriculture and the world at large. Lower fuel and water consumption will help reduce the cost of food and thus increase the quality of life of the regions affected, improve air quality and reduce the negative environmental impacts of agriculture in intensively farmed areas. Additionally, contribute to the reduction of the Greenhouse Gas (GHG) footprint of basic agricultural products as a result of the reduction of the energy consumed (fossil fuels, electricity). The significance of this reduction is already very high and is is anticipated to increase further as the global population rises and the intensity of global farming is expected to grow. The table below shows the various impacts of the implemented FMMIS (**Table 16**).

Table 16: FMMIS impact

Sector	Impact
Economy	Lowering the costs of farming will increase competitiveness of farmers with immediate impact on the rest of the economy, as Agriculture is the backbone of many countries. Especially for southern Europe where farming is a large percentage of the GDP, it will help increase competitiveness, dearly needed during this period. Even the cost of the equipment can be relatively low with a very small payback time and minimum training as they can be developed in a way to be user friendly.
Environment	The FMMIS can reduce the agricultural CO_2 emission footprint. Agriculture produces 500 Mt CO_2 yearly and this figure is not expected to drop until 2030. The fact that agriculture is the third biggest emitter of GHG's in Europe underlines the significance of this problem. In addition, it can minimize the negative effects of agriculture as water shortage, which is a major problem especially for the Mediterranean area.
Agriculture	Agriculture itself has the most to gain from the FMMIS, not only by the minimization of costs and increase in competitiveness, but also due to fine-grained and accurate analytics of the field operations, as well as from the capacity to automate most of the agricultural practices.
Society	Ensuring food and nutritional security, together with resource efficiency, and facing climate change is a major challenge for the society. The FMMIS

	address these needs by providing a resource-efficient eco-innovative solution helping on increasing farming production volume and minimizing resources consumption.

Moreover, the FMMIS can cover farmer’s needs as explained at the table below (
Table 17).

Table 17: FMMIS response in farmer needs

Needs	Response
To minimize energy consumption	• Minimising fuel consumption up to 50% in tillage and any other operations
To minimize water consumption	• Reduction of water consumption up to 30% in any type of crops compared to conventional farming
Reduce the environmental impact of agriculture and contribute to climate change mitigation	• Reduction (%) of tillage operation CO_2 emission footprint • Optimizing tillage quality and thereby minimizing soil disturbing effects • Reduce the chemical plant protection methods by mechanical weed protection principles which are system immanent to best management practice tillage • Reduction of using fresh water reserves, and capability to be applied in circular water solutions
Increasing the competitiveness of farmers	• Reduced inputs and higher yields improves farm’s economical sustainability
“Digital agriculture” for small farms	• Compatible with old “low tech” equipment • As the price of sensors is constantly dropping, farmers can purchase sensors and new IoT systems at very small prices.

4.1 Progress beyond the state of the art - Achievements

Through this thesis, a major number of innovative results and new knowledge were created. First of all, for the first time, the term Farm Machinery Management System (FMMIS) was introduced. The FMMIS covers all the new needs raised from the advantages that were held the latest years in Information Communication Technologies (ICT) and is totally based on new IR4 (Fourth Industrial Revolution) technologies. The FMMIS supports all the common protocols used in agriculture as ISOBUS, while it supports Unmanned Vehicles providing the ability of automated agricultural operations.

As the global population is constantly increasing and the cultivated areas are decreasing, new technologies will become a necessity as the only sustainable way for increasing agricultural output. It proved that Farm Machinery Management Information Systems in combination with IoT technologies can play critical role in this transition, and that they can contribute to the entering in the new era of holistic farm management, assisted by the extensive monitoring of the agricultural environment and automation of field operations. For proving the added value of FMMIS three different use cases of the FMMIS were implemented during this thesis.

At the first use case, a dynamometer capable to analyse the tractor–implement draft forces was developed. The dynamometer can retrieve data from sensors (load cells, fuel flowmeters) and from tractor ECU (through ISOBUS and CAN Bus), and by analysing the incoming data, it can propose in real-time the optimal working parameters to the tractor driver for reducing fuel consumption of for increasing tillage efficiency. The implementation shows a high level of originality, it is innovative and practice oriented and deals with a topic which is also of interest of the general public, as mentioned from CLAAS agricultural machinery manufacturer (**Figure 160**), which gave a fund of 8,000 Euros for conducting the specific use case.

CLAAS

we are happy to inform you that the Board of Trustees of the CLAAS Foundation gave authorization to support your above mentioned project.

Your research project shows a high level of originality, it is innovative and practice-oriented and deals with a topic which is also of interest to the general public. To determine instruments that reduce fuel consumption is of great interest. Herein the transparency of draft forces in various processes is a central basis and could form a good basis for farmers to facilitate decisions in tillage operations. Therefore, you are granted the amount of **8.000 Euro** which should be spent on material and equipment.

Please be so kind as to forward us an interim report after around 6 months and your final report upon completion of your project. Please provide us with the relevant receipts for documentation of your purchases and last but not least, please let us know your bank details.

Wishing you great success and looking forward to hearing from you.

Yours sincerely,

Uwe Lütkeschümer
Sylvia Looks

Figure 160: Funding of PhD thesis research from CLAAS agricultural machinery manufacturer

Moreover, the developed prototype was funded from Greek National ESPA EPAnEk 2014-2020 (Co-funded by the European Union) for its conversion into a commercial product. The project name was “EFFiTILL: An innovative system for EFFiciency optimization of TiLLage operations”, with grant agreement no. T1EΔK-05243. To achieve the goal of EFFiTILL project, the existing hardware prototype was redesigned for reducing its size (**Figure 161**) and for enriching it with additional features. In addition, a new Android application was developed for allowing tractor operators to easily use the system through their mobile phones (**Figure 162**).

Figure 161: EFFiTiLL’s hardware

Figure 162: Android Application

The second use case, was the development of a low cost unmanned Vehicle based on an ATV platform able to make various operations into agricultural harsh environment. These goal proved quite innovative and already big automotive companies are working on the same principles. For example, Honda presented autonomous vehicles based on ATV implementations[217] that can be used expect from agriculture[218] and on various other sectors including search and rescue, firefighting, and construction.

A significant achievement of the current use case is that the proposed unmanned vahicle was funded through ESMERA project EU call[219], at a project called IRTA. iRTA aimed to build a smart spraying apparatus tailored to the intricacies of treatment application in rough and steep slope terrains and on cultivations of high variability between plants, as is the grape. To achieve this, iRTA used the features of the developed robotic platform. The platform was equipped with a high-precision, low-waste spraying component, further improved by the incorporation of advanced AI models for optimizing treatment usage (**Figure 163**).

Figure 163: Installation of spraying component at the unmanned vehicle for the needs of iRTA project

Last use case, was the development of low cost IoT- high precision node for Precision Agriculture. The node has many innovative capabilities as very small size, extensive energy autonomy, automation capabilities, high accuracy, support of different types of sensors, IP67 protection, low price and “plug and play” operation.

Originally, the IoT system was developed for monitoring and controlling water to enable smart irrigation in open fields. As a result of its innovative characteristics the holistic system of the FMMIS and the IoT node was already tested in various environments as forestry (monitoring of environmental parameters in forests), large water infrastructures (monitoring of water quantities), meteorology (for monitoring the weather), and for smart cities with very promising initial results.

4.2 Impact in Greek agriculture domain

During this thesis, a major parameter that was taken into account was the Greek agriculture domain situation which is characterized from small farm size, reduced financial potential, and aging of the available workforce.

As a result, all of the implemented features of the FMMIS, both in terms of hardware and software, were developed in such way for overcoming the factors that minimizing the adoption of new agricultural technologies into Greek farming community. More specifically, the FMMIS components have a low price and a very small payback time leading early to profitability, they are easy to use by applying user friendly functionalities as plug and play methodologies and wizards' functionalities for minimizing complexity and training needs, and providing high accuracy and usability in the daily farm operations.

In addition, FMMIS implemented features are focused in minimizing the cost of farm operations dealing with two factors which are critical for Greek farming community, namely the cost of the fuels and the cost of the irrigation. As these cost are quite high, the FMMIS has the potential to reduce their consumption in a quite big amount, making the FMMIS a tool that can be adopted from Greek farmers as they can easily understand the usefulness of minimizing these costs.

Moreover, it suggests the implementation of low cost unmanned vehicles that can help on modernizing Greek farming sector, for minimizing even further the operational costs, and for reducing the labor needed for managing the farm, as the Greek farming workforce is following a negative trend.

Finally, the implemented FMMIS can have also a major impact in Greek economy and environmental sustainability, as the consumption of less fossil fuels will reduce Greek trade balance deficit, while the reduction of water overconsumption will minimize the effects of water shortage that Greece is facing.

4.3 Future work

The first steps on applying new technologies into agriculture have been achieved, but still a lot of time is needed in order these technologies to be applied in great scale into agricultural sector. This thesis proved that the usage of FMMIS approach using low cost equipment can be applied into agricultural sector. It can be used even in old equipment by retrofitting and modifying their existing equipment using low cost boards, sensors and actuators.

The usage of low cost systems is very promising but this transaction must be helped from the various vendors of agricultural machineries and technologies, for making them easy to use from the farmers. The experiments made till now showed that the reliability and effectiveness of low cost sensing, actuation and decision making is very high, but more tests must be done for validating the initial results.

In addition, a lot of work needs to be done, for further development of communication compatibility between the various agricultural technologies. Communication protocols as ISOBUS, and standardized languages for data exchange as JSON, can help to achieve this.

One of the most important stages of one future FMMIS integration will be the development of a robot fleet management module, which will allow the coordination and the management of a large number of different robots at various agricultural tasks. Using it, agriculture can move to a new era in which a fleet of unmanned vehicles will make most of the agricultural operations reducing the major role of agriculture in global emissions of the greenhouse gases carbon dioxide, nitrous oxide, and methane.

Finally, as the computer technologies (processors, controllers etc.) are constantly made cheaper, smaller and more powerful, a future FMMIS can be made even simpler by incorporating all the hardware capabilities into a small, low cost, energy autonomous hardware module with actuation capabilities, which will have all the functionalities needed for managing most of the farming operations, as ISOBUS and CAN Bus compatibility for retrieving and analysing agricultural machineries measurements and enabling actuation on them (e.g. variable rate application), controlling / automation capabilities for unmanned vehicles, and in-situ installation capabilities for retrieving measurements (e.g. weather data, soil data) and for automating farming operations (e.g. irrigation).

5 ANNEXES

5.1 Annex 1 – Face-to-face in-depth interview outline

Research question: drivers of adoption (non-adoption) of (ICT) innovations in agriculture

Topics:

1. **Organizational and professional tenure**

   a. Farm/company business (main activities), income
   b. Farm/company size, n. of employees, level of specialization
   c. Land and equipment ownership (if applicable)
   d. What is your role in the organization?
   e. What is your professional tenure?
   f. Can you tell me something about your education?
   g. Age, sex

2. **Technology adoption in agriculture**

   Think about an innovative technology that can be applied in a farm business (e.g.: a new system for cost control; a network of sensors that provide data about some characteristics of the soil; a particular controller for tractors that provide data about positioning, fuel consumption and level of crops growth, etc.).

   a. What do you think about technology adoption in agriculture? What is your level of knowledge about it (technology awareness)? Do you trust it?
   Note: in case interviewees are technological innovations providers (e.g.: precision agriculture technologies), FMIS providers, machinery, tractors and equipment producers, et c., they should be invited to think about their experience with agricultural farms. Question a) could then be: What do you think about technology adoption in agriculture? What is the general level of technology awareness you saw between farmers? How much is technology trusted, in your opinion?
   b. What is the role of ICT tools in agricultural practices, in your opinion? (Use of computers, smartphones, internet, equipment, technological devices, GPS, etc.)

c. What is the orientation of your farm/the farm you work in? What is your experience and your approach (short term/long term results and perspective)? What is your degree of confidence towards technology (use/no use, innovative capability, ease of use/difficulty of use)?

   Note: in case interviewees are technological innovations providers (e.g.: precision agriculture technologies), FMIS providers, machinery, tractors and equipment producers, etc., they should be invited to talk about their experience with agricultural farms. Question c) could then be: What is the orientation towards technological innovations of the farms you have worked with? What are the experiences you saw and farmers' approach (short term/long term results and perspective)? What is the degree of confidence towards technology you perceived in these farms (use/no use, innovative capability, ease of use/difficulty of use)?

d. Do you think that any of the factors of section 1 could affect or could have affected any decision about technology adoption? In which way?

3. ICT/Technological innovations' adoption process

<u>Think about the introduction of a new technology in a farm</u> (e.g.: a new system for cost control; a network of sensors that provide data about some characteristics of the soil; a particular controller for tractors that provide data about positioning, fuel consumption and level of crops growth, etc.).

a. What are the phases that compose the adoption process, in your opinion? (The adoption can be considered as a process, which is composed of different steps. The respondent should be able to enumerate the steps without any suggestion from you. Then, you can consider the following steps: initial conditions – awareness – trial - adoption/non adoption)
b. What are the most important factors that affect the decision process (both positively and negatively)? Can we give an evaluation of different relevant factors? (Try to identify the factors without providing suggestions to your respondent. Then you can provide some suggestions and discuss about them: usefulness, connected with the most relevant information; ease of use; compatibility with existing practices; observability of results; existing skills; relative advantages and benefits; education, interest for innovation and attitude towards change, etc.). What about external influences (market, consultants, self-awareness)?

c. Do you think that external qualified support could help in adopting ICT tools? Do you think that any kind of trial (e.g. involvement in a pilot project) could be useful and effective to enhance adoption?
d. Can you please link the above mentioned phases of the adoption process with the associated factors? (use the diagram at the end of this section)

4. Opportunities and limitations

a. Do you perceive any benefit from/in adopting ICTs in farm businesses that can affect the decision about adoption? On which farm "function" (field operation management, reporting, site management, finance, etc)? Why – what kind of benefit? (Interaction with human, structural and economic resources). Did you experience it or is it an opinion (personal opinion, external influences, and information sources)?
b. Do you perceive any limitation from/in adopting ICTs in farm businesses that can affect the decision about adoption? On which farm "function" (field operation management, reporting, site management, finance, etc)? Why – what kind of limitation? (Interaction with human, structural and economic resources). Did you experience it or is it an opinion (personal opinion, external influences, and information sources)?
c. If you were aware about ICT and technological innovations' potentialities (e.g.: predictive skills, recommendations, costs and time savings, resources management, etc.), which of them could be of interest for farm businesses and could enhance the decision about adoption, in your opinion?
d. What do you think ICT tools are missing, to satisfy farmers' needs?

5.2 Annex 2 – Focus group discussion guideline

Brief explanation for the guideline:

Graphical hints:

- In the cells (see examples below) research-relevant questions are shown:

Main question: *important question of the section.*

Secondary question: *relevant topic, connected to the main question.*

Note: All the questions included in the cells must be read out loud!

- In normal characters, actions to be performed are listed.
- In italics suggestions are reported:

- *"Text in italics, between inverted commas"*: text that must be read loudly!!

- *Text in italics (not between inverted commas)*: questions and suggestions for the follow up.

- TEXT IN CAPITAL LETTERS: specific instructions are given.

Questionnaire

- Welcome participants
- Record logistic information about the focus group (date, starting time, location, n. of participants recruited and n. of participants missing)

Introduction (max. 10 min.) – 0 h :10 min

In this section, the moderator should do the following things:

- Brief presentation (name, affiliation, professional tenure);
- Brief explanation about audio recordings (make the participants aware that their conversations are going to be recorded);
- Assurance about privacy policy (data will be treated and analyzed jointly, and participants' identity will remain anonymous);
- Brief explanation about focus group discussion rules and operation: each participant can express his/her ideas and opinions; there are no correct or wrong answers, and the aim of the discussion is to allow all the participants to express their opinion, even when divergent;
- Brief explanation to make participants understand that a collective discussion/conversation is requested, to talk about the topics under analysis. The moderator will present themes and topics to talk about, and participants will discuss together on those arguments. Participants should not address their comments and opinions to the moderator, whose tasks are only to make the discussion focus on the relevant topics, and stimulate it in case of need;
- Start with the first question (participants are invited to introduce themselves).

Question: "*I would like to start with a brief presentation of each participant; so, I invite you to introduce yourself briefly, tell the others your name, your age, where you are from and what is your job".*

THE MODERATOR SHOULD WALK AROUND THE TABLE, TO AVOID TO BE ADDRESSED BY PARTICIPANTS WHEN THEY START ANSWERING THE QUESTIONS. THE MODERATOR IS RECOMMENDED TO STAND BEHIND THE PARTICIPANT WHO IS TALKING (IN ORDER TO HIDE BEHIND HIM/HER AND TO FORCE HIM/HER TO TALK WITH THE OTHER PARTICIPANTS. FINALLY, THE MODERATOR SHOULD USE THE SNOWBALL TECHNIQUE (WHEN HIS/HER ANSWER IS COMPLETED, EACH PARTICIPANT SHOULD INVITE ANOTHER PARTICIPANT TO START TALKING), IN ORDER THAT EVERYONE CONTRIBUTES TO THE DISCUSSION.

Section 1. Warming-up (max. 10 min.) – 0 h :20 min

"Now, let's start with the first part of this discussion. Let's start from something easy, to break the ice. Tell me more about your company and you. I invite each participant to tell the others about his/her company business (main activities), income and size (areas, n. of employees, level of specialization); company's ownership (land/equipment); his/her role in the organization, professional tenure and education,".

PARTICIPANTS SHOULD START ANSWERING THE QUESTIONS. THE ASSISTANT(S) SHOULD DRAW A TABLE ON THE BOARD AND NOTE THE ANSWERS OF THE PARTICIPANTS.

Main question: *"Do you think that any of these features can affect your decision about the adoption of technological innovations or ICT tools? Can you tell me in which way?".*

THE MODERATOR SHOULD WALK AROUND THE TABLE ASSURING THAT EACH PARTICIPANT EXPRESSES HIS/HER OPINION. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE BOARD, LISTING THE OUTCOMES.

Section 2. Approach towards technology adoption in agriculture (max. 20 min.) – 0 h :40 min

“Now I would like to about the adoption of technological innovations in agriculture. Think about an innovative technology that can be applied in a farm business (e.g.: a new system for cost control; a network of sensors that provide data about some characteristics of the soil; a particular controller for tractors that provide data about positioning, fuel consumption and level of crops growth, etc.)”.

Main question: "*What do you think about technology adoption in agriculture? Do you know any example? What is your level of knowledge about it? Do you trust it?*

THE MODERATOR SHOULD WALK AROUND THE TABLE ASSURING THAT EACH PARTICIPANT EXPRESSES HIS/HER OPINION. IN CASE OF NEED, THE MODERATOR SHOULD PROVIDE ADDITIONAL EXAMPLES OF TECHNOLOGICAL INNOVATIONS TO CLARIFY THE QUESTION.

-DISCUSSION-

Secondary question: "*In your opinion and for what concerns your experience and your knowledge, what is the role of ICT tools in agricultural practices? What are they useful for, or what can they be useful for?*

THE MODERATOR SHOULD STIMULATE PARTICIPANTS TO EXPRESS THEIR OPINION AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

“Now I would like to invite you to think about your company and its orientation towards the adoption of technological innovations. I would like you to think about your situation for few minutes and tell me what is your experience and approach.”

Main question: “What is the orientation of your company/the company you work in, towards innovative technologies and their adoption? What is your approach?”

THE MODERATOR CAN HELP PARTICIPANTS BY USING THE FOLLOWING SUGGESTIONS:

“In case you adopted an innovative technological tool, what was the main aim that drove you in adopting it? Where you thinking on a short or long term results’ perspective? Why?”.

THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

Secondary question: “What is your degree of confidence towards technology? Do you use it? What kind of technological innovations have you tried or used? Which were the main obstacles, if any?”

THE MODERATOR MUST SOLICITATE PARTICIPANTS TO TALK ABOUT THEIR EXPERIENCES AND APPROACHES TOWARDS TECHNOLOGICAL INNOVATIONS, TRYING ALSO TO UNDERSTAND THE UNDERLYING ATTITUDE TOWARDS INNOVATION.

-DISCUSSION-

Section 3. ICT/Technological innovations’ adoption process (max 25 min.) – 1 h :05 min

“Now I would like to invite you to think about the decisional process concerning the adoption of technological innovations. Let’s suppose that you have to decide about the introduction of a new technology in a company, for instance your company. When we talk about new technology we mean, for example, a new system for cost control; a network of sensors that provide data about some characteristics of the soil; a particular controller for tractors that provide data about positioning, fuel consumption and level of crops growth, and so on.”

Main question: “What are the phases that compose the adoption process? What are the steps you undertake before coming to a final decision?”

THE MODERATOR SHOULD STIMULATE PARTICIPANTS TO EXPRESS THEIR OPINION AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

IN CASE PARTICIPANTS ARE NOT ABLE TO UNDERSTAND THE QUESTION, OR HAVE SOME DIFFICULTIES IN ENUMERATING THE PHASES OF THE ADOPTION PROCESS, THE MODERATOR CAN GIVE THE FOLLOWING SUGGESTION:

“The adoption of a new technology can be considered as a process, which is composed of different steps. You usually face an initial condition (where you have an amount information which depends on many factors and it’s different according to your different conditions); then, you face an “awareness” process; then you can have a trial phase, and finally you can approach the decision to adopt or not to adopt. Do you agree with these steps?”

THE MODERATOR SHOULD STIMULATE PARTICIPANTS TO EXPRESS THEIR OPINION AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

“Once the steps of the decision process are defined, now I would like to invite you to think about what are the most important factors that affect the decision process, in the different steps. I give you few minutes to think about the factors that can affect the decision to adopt or not a technological innovation, and their relevance. Some of them will be strong and others will be weaker; you can mark them by using a scale, from +++ **very strong** to **--- affecting, but very weak**. I kindly ask you to list the factors in the paper sheet.”

Main question: “What are the most important factors that affect the decision process, both positively and negatively? Can you give an evaluation of the different relevant factors?”

THE MODERATOR SHOULD LEAVE SOME MINUTES TO PARTICIPANTS TO WRITE DOWN THEIR OPINIONS. THEN, THE MODERATOR SHOULD INVITE PARTICIPANTS TO SHARE THEIR OPINIONS WITH OTHERS, AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

IN CASE PARTICIPANTS ARE NOT ABLE TO ENUMERATE THE FACTORS, THE MODERATOR CAN SUGGEST SOME EXAMPLES (usefulness, connected with the most relevant information; ease of use; compatibility with existing practices; observability of results; existing skills; relative advantages and benefits; education; attitude towards change and innovation, etc.).

-DISCUSSION-

“Once the steps of the decision process and the affecting factors are defined, I would like to invite you to link the factors you identified some minutes ago to the different steps of the decision process, previously mentioned. Every step of the decision process is characterized by the influence of some of the factors you mentioned; then, I kindly ask you to use the diagram you were given and to fill in the rectangles (with the name of the phases of the decision process) and the balloons (with the name of the most relevant factors affecting or characterizing that phase of the decision process).

Main question: “Can you please link the phases of the adoption process with the associated factors?”

THE MODERATOR SHOULD LEAVE SOME MINUTES TO PARTICIPANTS TO FILL IN THE DIAGRAM. THEN, THE MODERATOR SHOULD INVITE PARTICIPANTS TO SHARE THEIR OPINIONS WITH OTHERS, AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD DRAW THE DIAGRAM ON THE BOARD, AND NOTE THE ANSWERS ON THE DIAGRAM, COLLECTING THE OUTCOMES.

-DISCUSSION-

Secondary questions (if the investigated aspects did not emerged from the previous question): “What about external influences (market, consultants, etc.)? Do you think that external qualified support could help in adopting technological innovations? Do you think they have any relevance in the adoption decision process? Which phase of the decision process they affect? Do you think that any kind of trial (e.g.: involvement in a pilot project) could be useful and effective to enhance adoption? Have you any experience about that?”

THE MODERATOR SHOULD INVITE PARTICIPANTS TO SHARE THEIR OPINIONS WITH OTHERS, AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

Section 4. Opportunities and limitations of ICT/Technological innovations (max 15 min.) – 1 h :20 min

“We are coming to the conclusion of this focus group. The last thing I would like to ask you is to write down the benefits and the limitations deriving from adopting technological innovations that could affect the decision about the adoption. In addition, I would like you to think about the “area(s)” of the company in which you see the biggest opportunities/limitations deriving from the adoption of technological innovations”.

Main question: “Do you perceive any benefit or limitation from adopting technological innovations in companies that can affect the decision about adoption? On which “area” (e.g.: field operation management, reporting, site management, finance, etc)?” What kind of opportunity/limitation and why? Did you experience it or is it an opinion (personal opinion, external influences, and information sources)?**”**

THE MODERATOR SHOULD LEAVE SOME MINUTES TO PARTICIPANTS TO WRITE DOWN THEIR OPINIONS. THEN, THE MODERATOR SHOULD INVITE PARTICIPANTS TO SHARE THEIR OPINIONS WITH OTHERS, AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

Main question: “What do you think technological innovations are missing, to satisfy farmers’ needs? If you were aware about their potentialities and effects (e.g.: predictive skills, recommendations release, costs and time saving, resources management, etc.) which of them could be of interest and effective in orienting the decision about adoption?”

THE MODERATOR SHOULD INVITE PARTICIPANTS TO SHARE THEIR OPINIONS WITH OTHERS, AND DISCUSS TOGETHER. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

-DISCUSSION-

Conclusion (max 5 min.) – 1 h :25 min

"*Before closing the focus group discussion, I would like to ask whether you need to add anything to the discussion.*

Main question: *"Is there anything else that you would like to add or to remark? If you should think about the main topic of this discussion, namely drivers of technology acceptance and adoption in agriculture, does anybody want to add anything, or is there anything left to say?"*

THE MODERATOR SHOULD LET PARTICIPANTS THINK ABOUT WHAT TO SAY IN ADDITION, AND MUST ASSURE THAT EACH PARTICIPANT IS ALLOWED TO SPEAK. THE MODERATOR SHOULD WALK AROUND THE TABLE. THE ASSISTANT(S) SHOULD NOTE ANSWERS ON THE ABOVE-MENTIONED BOARD, LISTING THE OUTCOMES.

Afterwards

THE MODERATOR AND THE ASSISTANT(S) MUST COLLECT ALL PARTICIPANTS' NOTES AND NOTES FROM THE BOARD.
THE MODERATOR MUST THANK PARTICIPANTS AND CLOSE THE FOCUS GROUP.

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