PROJECT NO: FP6-508465

MICRODIS

Soil Disinfestation Microwave System As An Alternative To Methyl Bromide

Co-operative Research (Craft)

Horizontal Research Activities Involving SMEs

Publishable final activity report

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Final Version

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PROJECT EXECUTION

SUMMARY OF OBJECTIVES

In intensive agriculture and more specifically in greenhouse management, it is necessary to effectively control weed seeds, nematodes and various pests and pathogens living in the soil. The problem is currently handled either by steaming the soil, by using various fumigants or by soil solarisation. Conventional steaming systems are very bulky, not easy to operate, can pollute the environment due to harmful emissions and can be very inefficient. Furthermore, fumigants are heavy pollutants and for this reason their use within the European Union was prohibited in the year 2001. In particular, Methyl Bromide was defined as a chemical that contributes to the depletion of the Earth's ozone layer under the Montreal Protocol of 1991. Methyl bromide's reign as the gold standard of soil fumigants thus became tarnished as its ozone depleting properties surfaced. It will prove less expensive to eliminate methyl bromide and seek alternatives than to finance the medical costs associated with the increase in skin cancer cases caused by increased exposure to harmful UV rays, the increase in UV radiation also causes damage and destruction to crops.

Methyl bromide is a highly effective fumigant used to control insects, nematodes, weeds, and pathogens in more than 100 crops, in forest and ornamental nurseries, and in wood products. There is no known single alternative fumigant, chemical, or other technology that can readily substitute for methyl bromide in efficacy, low cost, ease of use, wide availability, worker safety, and environmental safety below the ozone layer. Unless viable alternatives are found, European farmers and other users will be at a disadvantage when competing with agricultural products produced in developing countries, where methyl bromide will continue to be available for several years after the European phase out. The objective of this project is to develop a system of fumigation of cultivation soil via electromagnetic radiation in the range of 950MHz to 2450 MHz. Such a system will fulfil a clear commercial need on a European level given that effective alternatives to methyl bromide are urgently needed if the European crop market is to compete successfully against production in developing countries, as well as from US production, where methyl bromide will be in use until 2015.

From a scientific point of view, the aim of this project will be to develop a system for the fumigation of cultivation soil via electromagnetic radiation in the range of 950MHz to 2450 MHz. The scientific challenge of the project lies in developing a microwave system which will be as user friendly and effective as possible and which will need to be successful in destroying a wide variety pathogens and pests, while not destroying vital nutrients and organic matter present in the soil, which are essential for the healthy growing of crops. It is important that the developed system is as cost effective as possible and this will need to be forefront in the development work carried out by the Research Centres. Microwave systems for the irradiation of large amounts of material, as will be required in this application, proves very costly in terms of energy consumption. Therefore, considerable scientific effort will need to be directed at making the system energy efficient.

CONTRACTORS INVOLVED IN THE PROJECT

Partic. Role*	**Partic. no.**	**Participant name**	**Participant short name**	**Country**	**Date enter project***	**Date exit project****
CR	1	KIUP S.A	KIUP	Spain	M1	M24
CR	2	JCB ELECTROMECANICA S.A	JCB	Spain	M1	M24
CR	3	AGRIFUTUR S.R.L	AGRI	Italy	M1	M24
CR	4	SAIREM	SAIR	France	M1	M24
CR	5	KAZANLI-MERSIN	KAZA	Turkey	M1	M24
CR	6	YENI TASKENT BELEDIYESI	BEL	Turkey	M1	M24
CR	7	THE APPLE FARM	APPLE	Ireland	M1	M24
CR	8	BIO-RESSOURCES	BIORT	France	M1	M24
CR	9	CAMPOSOL	SOL	Portugal	M1	M24
CO	10	CRIC (Centre de Recerca i Investigació de Catalunya, S.A.)	CRIC	Spain	M1	M24
CR	11	PERA	PERA	UK	M1	M24
CR	12	PLANT PROTECTION RESEARCH INSTITUTE	PPRI	Turkey	M1	M24
CR	13	FKK (Feltalálói es Kutató Központ Szolgáltató, KFT - Innovation and Research Center Services Company Limited)	FKK	Hungary	M1	M24

*CO = Coordinator
CR = Contractor

SME PROPOSERS

1. KIUP S.A./SPAIN

Business Activities: Spanish based engineering company specialising in agricultural machinery. They carry out Business Activity specific designs for their clients and maintenance of machinery and equipment. They also develop their own products and have the capacity to manufacture and sell the system developed during this project. They already hold a patent for the treatment of soil using microwave techniques, however, due to problems relating to the cost and energy consumption of the equipment, they were unable to arrive at a marketable system.

Role in RTD: They will contribute their microwave expertise to the project and will be involved in WP3. They will also be involved in defining specifications and market requirements.

Expected Benefits: KIUP are very interested in this project as in the past they have been keen to arrive at a cost effective and marketable microwave disinfestation system and are very convinced of the market need for an alternative for MeBr. They envisage an increase in their turnover due to manufacture and sale of components to be implemented into the microdis system, as well as sale of the actual system itself.

2. JCB ELECTROMECANICA S.L/SPAIN

Business Activities: JOAN COSTA BOFILL S.L. (JCB) is a Spanish SME, specialising in the design and manufacture of mechanical and electronic systems for the manufacturing industry. JCB has vast experience in the implementation and adaptation of systems into agricultural machinery, such as soil removal designs for the agricultural sector.

Role in RTD: They will lend their experience in soil handling and soil removal to the design of a system of transferring the soil from the ground into the microwave cavity. They will also be involved in defining specifications and market requirements.

Expected Benefit: They envisage an increase in their turnover due to manufacture and sale of components to be implemented into the microdis system, as well as sale of the actual system itself.

3. AGRIFUTUR S.R.L/ITALY

Business Activities: Agrifutur S.r.l. is a small company (member of Assobiotec companies) active in the fields of plant and animal growth, food processing, animal feed and the environment. Its technologies include fermentation, process monitoring and control and purification and separation. Among its product range are nitrogen-fixing bacterial inoculants for plants; biological inoculants for plant growth; silage inoculants for maize and grass; bacterial starter-cultures for meats such as salami. With respect to insect biocontrol, Agrifutur produces and commercialises Melocont-Pilzgerste, the first fungal BCA, which can be used without any restrictions in Austria, since June 2000. The company has close relations to national and international agro-industrial company and farmer organisations. They have participated in several EU-funded projects (i.e BIPESCO project; Eclair: 1990-1993- biological inoculant for seed/plant establishment; Bridge: 1991-1994- Genetic and molecular approaches of the physiology of bacteroids; FIXNET: 1997-2000- Regulatory and metabolic networks related to nitrogen fixation in the legume nodule). Given their experience they will be very much involved in testing the effect of the microwavef.

Role in RTD: system has on the biological content of the treated soil, in terms of bacteria and fungi; growth promoters; anthagonistic and entomophatogenic micro-organisms, etc. They will investigate the survival and growth rate of beneficial micro-organisms and look into how this can be dealt with and compensated.

Expected Benefits: They are well aware of the need to find viable and environmentally sound soil disinfestation techniques and they envisage an increase in their turnover through the sale of the system. They will also gain invaluable know-how through their involvement in the research. They will be very active in dissemination of the results of this research project through their large network of contacts.

4. SAIREM S.A./FRANCE

Business Activities: SAIREM was set up in 1978 and is today one of the most important manufacturers of microwave and radio frequency systems for laboratory and industry in France. They are the only company who has specialist knowledge of both these technologies and are thus able to combine these two areas of expertise to provide optimal solutions for many different applications. Thanks to their intrinsic qualities, microwave and radio frequency can be used in many fields- laboratories, rubber, plastics, wood, textiles, paper, cardboard, chemical and para-chemical industries, composites material, food processing or plasma are areas from which we have already conceived equipment.

Role in RTD: They will contribute their microwave expertise to the project and will be involved in WP3. They will also be involved in defining specifications and market requirements. They will also be very much involved in identifying new applications for the microdis system.

Expected Benefits: They are very interested in this project as they are interesting in being involved in the development of microwave technology for disinfestation applications. They envisage an increase in their turnover due to manufacture and sale of components to be implemented into the microdis system, as well as sale of the actual system itself.

5. KAZANLI-MERSIN/TURKEY

Business Activities: This company is a Turkish farm that is involved in the cultivation of peppers. They cultivate some 50 da.

Role in the Consortium: They will be involved in defining market needs and the specifications for the proposed microwave soil disinfestation system. They will also be heavily involved in the field validation of the system.

Expected Benefits: Given the nature of their cultivation they are very aware of the need to find an alternative to MeBr and they are very keen to be involved in this research project. Soil fumigation is problem for farmers and safe and environmentally accepted alternatives would be of great benefit to cultivators.

6. YENI TASKENT BELEDIYESI/TURKEY

Business Activities: They are a pioneering farm based in Turkey and involved in the cultivation of peppers.

Role in the Consortium: They will be involved in defining market needs and the specifications for the

proposed microwave soil disinfestation system. They will also be heavily involved in the field validation of the system.

Expected Benefits: Given that the owner of this farm is an agricultural engineer he is very keen to build up his technical knowledge and know-how by being involved in this research. They are also victims of the problems associated with soil fumigation and are aware of the severe damage that chemical fumigants have on the environment. They are keen to lead the way in Turkey in the adoption to a cleaner approach to farming and they are also eager to improve the safety of their work environment.

7. THE APPLE FARM/IRELAND

Business Activities: The Apple Farm is located in county Tipperary in the south of Ireland. They are engaged in a number of activities on their farm. Among these is a Camping & Caravan park, fruit production units including apples, pears, plums, strawberries and raspberries as well as bouquet apple juice production. They have a farm shop from which their products are available all year round. They currently grow about 3 acres of strawberries and one acre of raspberries, and also plums, apples and pears.

Role in the Consortium: They will be involved in defining market needs and the specifications for the proposed microwave soil disinfestation system. They will also be heavily involved in the field validation of the system. Mr. Con Traas, the owner of the farm, is also a lecturer in Horticulture at the University of Limerick in Ireland and he will be able to contribute his scientific knowledge to the project wherever applicable and he will also play a key role is dissemination of the result of the research through his network of University contacts in both Ireland and the UK.

Expected Benefits: Mr. Traas he is very keen to build up his technical knowledge and know-how by being involved in this research. He is also eager to exploit the results of this project on his own farm.

8.-BIORT BIO-RESSOURCES/FRANCE

Business Activities: Bio-Ressources Technologies (BIORT) is a French SME that was established in 1998 dedicated to the production and sale of composting technologies and equipment, as well as carrying out tests for assessing compost quality and compost appreciation. Biort have unique know-how in the production of quality compost at low costs. They are very interested in expanding their know-how and the range of equipment and products they offer. They are well networked within the agricultural sector in France and other countries and are keen to take advantage of their existing sales network to market the microdis system.

Role in the consortium: They will assist in carrying out the market research and defining the specifications for the system. They will also be involved in looking into the issue of the nutrient contact of microwave disinfected soil.

Expected Benefits: : BIORT are keen to expand their business by meeting the soil disinfestation needs of farmers and they envisage an increase in turnover through the sale of the system.

9.-CAMPO SOL/PORTUGAL

Business Activities: CampoSol is a pioneering farm based in Portugal and involved in the cultivation of tomatoes, peppers, onion, etc.

Role in the consortium: They will be involved in defining market needs and the specifications for the proposed microwave soil disinfestation system. They will also be heavily involved in the field validation of the system.

Expected benefits: In Fact he has several problems with nematodes and he will exploit the results of this project on his own farm.

1. PROJECT RESULTS OVERVIEW

1.1 RESULTS DURING THE FIRST PERIOD

During first steps of the project, a market survey was carried out. The objective was to ensure that the technology developed corresponds to the needs of the market place, the price sensitivity, as well as the acceptance of the proposed equipment into the market. A questionnaire and a cover letter introducing the project and its objectives was draft in different languages. Several personal interviews were made at the facilities of different greenhouse farmers, a massive emailing was done, and a telephone survey was carried out to gain an improved and more in-depth overview. Based on this market survey as well as the experience of the partners, the general input requirements were defined.

In Parallel to the survey, a study of the most common microbial life affecting typical crops was done (task 2.1). The goal of this task is to provide the biological information required for the development of a new soil disinfection technology alternative to MeBr fumigation. This task describes the plant pathogens that are currently controlled in the EU with MeBr-based fumigants, and their biology.

On the other hand, we performed a study about the determination of the parameters in typical EC soils (Task 2.2). Given the European nature of the project it is of utmost importance that the *microdis* system is developed so that it will serve the requirements of the European crop soils. The main goal was to determine which soil parameters affects the proposed disinfestation method and how.

The next step in the project was the Preparation of different samples to irradiate. Taking into account the information gathered in the Task 2.1 and Task 2.2, soil samples were prepared. The soil samples collected and transported has been prepared and stored in specific sealed box controlling the temperature conditions.

For the experiments carried out during the first year of the project the consortium decided to use the same type of soil (Sandy) for all the experiments changing some physical parameters such us the % humidity. The soil was provided from different partners of the consortium (Kazanli Mersin and Yeni Taskent Belideyesi).

In the WP2, different tasks were envisaged to investigate alternative techniques to conventional microwave radiation in order to improve the energy efficiency. After some discussion about disinfestation methods, the consortium decides to do experiments also using Radio Frequency heating (27MHz) and high electric field pulses, which seems a suitable and realistic technology.

A 1kW, 2,45GHz microwave oven an a 27MHz, 450W RF oven was used for the trials at laboratory scale. The microwave oven was modified to measure the power absorbed by the soil. The microwave oven can apply different microwave powers and exposition times. The trials with the high electric field pulses were done in a externat laboratory (Veiki labs) at Budapest (Hungary).

The results and conclusion extracted from the investigation of the three proposed techniques determined the design rules for the development of the final prototype. The main advantage of RF and high electric field pulses over microwaves is that allow the application of the treatment directly into the soil because of the good penetration of the energy while the application of microwave requires lifting up the soil due to the strong attenuation of soil to microwaves.

The results at laboratory scale, showed that microwaves appears more feasible that RF or the application of high electric field pulses. The ratio of soil disinfection were more or less the same for microwaves and RF. However, the cost of 1kW of RF is higher than 1kW of microwaves. The application of high electric field pulses (3kV/cm, 10 pulses of 50 μs duration) in soil didn't affect the living micro-organism (nematode and diseases).

The results at laboratory scale confirmed the idea to develop a soil treatment system based in microwaves.

The development of a 18kW microwave power was proposed. A first concept design of the microwave prototype was made. The concept design was based in the use of 3 microwave cavities (6kW power each) attached at the rear part of a soil lifter.

The concept design (task 3.1) foresaw the use of low cost and low power domestic magnetrons. It was also proposed the design and manufacturing of microwave components (stub tuner, launcher, cavity, etc) to reduce the total cost system.

Taking into account the given technical specifications, a selection of the microwave generators (task 3.2) and sensors (task 3.3) for the control of process were made. The control system was based in the use of temperature sensors to control the speed of the process.

A selection of the power source to run the microwave system was also made. The size, yield and autonomy was taken into account as well as the ease of refuelling and noise levels emitted (task 4.1).

A conceptual design of the soil removal (soil lifter) system was also presented. The system takes into account that the earth that is being returned to the cultivation area is completely sterilised, and during the process of feeding soil to be treated to the system, none of this falls on sterilised ground. The system of collecting and depositing the soil has been designed from modifications made to conventional agricultural machinery in existence on the market. A market search has been carried out on the most common soil collection machines. Different designs will be proposed during the frist stage of the second year.

1.2 RESULTS DURING THE SECOND PERIOD

During the second part of the project three micrwave cavities were contructed based in the previous designs. Several samples of soil were prepared for the test and characterization of the cavity. The characterization of the cavity includes measurements of impedance matching between the microwave source and the soil. Differences in soil such us humidity and composition has been studied in order to determine is the adaptation of the system is good enough to avoid the need of continuous calibration. The temperature profiles achieved inside the cavity has also been studied.

On the other hand, a soil collection machine has been developed based in a existing machinery. A second hand machine for vegetable collection was modified to lift up the soil. The machine is capable to lift up the upper 20cm of soil in real conditions. The machine has a soil storage capacity (in a hopper) of 1200kg (1m3). The selected machine has a conveyor belt which had to be adapted for the transportation of soil (rubberized belt). A feeding system was adapted and is based in three independent worm gear (screws) attached to an electric 250 W motor (1 per worm gear). A hopper was also attached at the rear part of the machine to allow the disinfection of the soil in batches.

Different security systems has been implemented (task 4.4). A microwave radiation monitor has been mounted to prevent the radiation of microwaves scapes. A system for the control speed of the process has also been implemented. The speed of the process is controlled adjusting the speed of the worm gear electrical motors through an programmable 3 phase inverter.

Finally, the different parts of the microdis machines has been mounted and several test at field has been carried out. Analysis of soil has demonstrate that the system is capable to treat 3-4 tonnes of soil per hour using 20kW of electrical energy.

SUMMARY OF MILESTONES

The general milestones of the project follow, updated with the actual achievements of the project:

✓ To specify market need requirements → M3: A specification of the market requirements was done thus allowing the definition of technical specifications for the final system. This milestone was achieved performing an intensive mailing and many personal interviews with companies of the sector. The conclusions derived from this study reinforced the idea to investigate more in depth other technologies proposed in this proposal like the application of high electric field pulses or radio frequency heating at 27Mhz.

✓ Determine whether the microbiological functions of the soil are suitable for cultivation purposes after radiation. Verify whether the vitality of the soil is optimum for cultivation. → M12:

Three disinfection methods (I.e. high electric field pulses, Radio frequency heating at 27MHz and microwave heating at 2,45GHz) were tested using real samples of infected soil. Results showed that the best alternative for soil disinfection was microwave heating. The analysis made immediately after the treatment with microwaves indicates that microwave heating affects both types of nematodes (beneficial and non-beneficial) and diseases. However, a posterior (3 weeks) analysis (I.e. nematode and disease counting) of the treated samples shows a strong repopulation of beneficial nematodes (free living) compared with the root knot nematodes which remains at lower limits.

✓ In accordance with the obtained data, we will be able to determine what power it will be used to arrive at a system that can be used in an industrial way, as well as the complementary effects of other alternatives, such as high power pulses. → M12:

Results confirm that the best disinfection method for soil was microwave heating. The efficiency in terms of soil disinfection (ratio power/soil volume) was determined at laboratory scale. After the results, the consortium agrees in the construction of a 18kW prototype for the trials at field.

✓ Development of a resonant cavity and associated soil transport system. → M12: A concept design of the microwave cavity as well as the determination of physical parameters was made for the M12. Physical parameters of the cavity were determined by simulation of the microwave field distribution inside the cavity.

During the second part of the project, the objective was to develop the microwave sources. Initially, it was planned to use industrial microwaves sources. However, the members of the consortium suggest using domestic magnetrons to reduce the cost of the elements. It was necessary to develop all the parts of a microwave source (Launcher, stub tuner and cooling system). The cost of a “Microdis” microwave source (900W, domestic magnetron) has a total cost of 300€ while the cost of an industrial unit (1.2kW) cost about 4000€ or 5500€ for a 2kW system.

✓ Selection of microwave sources→ M12: A microwave source based in a low cost domestic magnetron (900W) was selected. The cost of this unit is about 100€.

✓ Development of the resonant cavity control system→ M18: The reason was the definition of the technology to be used during the project (microwaves instead of RF or high voltage pulses). The control system of the resonant cavity is composed mainly of temperature sensors (thermocouples) to measure the final temperature of the soil. Additionally, it has been implemented a current monitoring system to monitor the consumption of the magnetrons. In case of a fail in the magnetron the current consumption will be detect the problem. A final version was integrated into the final prototype.

✓ Development of safety systems for the cavity→ M12: The safety systems for the cavity are a microwave radiation monitor, which forces a shutdown of the whole system in case of microwave escapes and the control of the temperature in the magnetron. A temperature switch (bimetallic) interrupts the power supply of the magnetron when the temperature in the Heatsink achieves 70ºC.

✓ Testing and characterisation of the system→ M12: The stability of soil impedance inside the cavity has been analyzed using differen types of soil and changing the properties (soil moisture). The results indicates a good stability of the impedance respect the changes introduced into the soil which reduces the complexity of the system (do not require a continuos calibration).

It has been also studied the temperature profiles of the soil inside the cavity. The results indicates that the physical dimensions are suitable for the application. A protocol for impedance matching between microwave source and soil has been also developed. Different tests of the power extracted from the source have been made to assure the absence of reflection inside the cavity.

✓ Design and development of soil removal and deposition systems. → M23: A draft of the design was presented in the month 12. The last physical version of the soil lifter was validated at Month 23 being the M26 the ending of the project. The soil lifter system has been designed modifying existent machinery used for the collection of vegetables.

✓ Design and development of the mechanic and electric interfaces within the cavity system → M22; This milestone was achieved during the second period of the project. The mechanical interfaces with the cavity are a conveyor belt and a soil feeding system based in a worm gear. The conveyor belt lifts up the soil from the ground using a kind of dustpan. The conveyor belt was adapted for the transportation of the soil (rubberized belt). The feeding system is driven by 250W electrical motors. The speed of motors is controlled through a 3 phase inverter. This milestone was achieved during the second part of the project (Month 20).

✓ Design & development of security systems → M12; The design, development and implementation of the safety systems are related with the connection of the system to the electrical network. A shutdown of the microwave system is made in case of short-circuit. It is a simple but effective protection system based in a circuit breaker (for short-circuits) and an earth leakage detector switch.

✓ Design and development of a control system via PLC→ M20; The control of the system is related to the control of the speed of the process. Other functions like shutdown of the system in case of microwave escapes, short-circuits, overheating of the microwave units, have been also considered and implemented in other tasks. The control of speed is made using a programmable electronic frequency inverter. This milestone was achieved during the second part of the project (Month 20).

✓ Results from complementary alternatives→ M12: Complementary alternatives were based in the pre-treatment of soil by using chemicals in lowers quantities or pre-heating the soil through other waste heat sources like the exhaust gases of the tractor, heat generated by the microwave system, etc. However, none of these alternatives seems to be useful in the praxis. In the case of reuse the heat, its step requires a complex and expensive installation of heat pipes. In the case of the chemicals, the partners were not comfortable with the idea.

Other option was to pre-heat the soil using the current soil solarisation method to reduce the energy required for heating up the soil to 50ºC. Current soil solarisation method can achieve temperatures above 35ºC-40ºC in the upper 10-12 cm.

✓ System integration → M20: The complete integration of the prototype was achieved at Month 24. However other parts of the system (i.e. microwave system, soil lifter) were integrated per separated before (M20).

✓ Verification of the safety system & system testing → M24: The microwave system and the soil lifter machine were tested by separate. The tests were done at month 20. After testing some modifications were required in both systems (microwave and lifter) and the complete system was verified at M24.

✓ Prototype characterisation → M24. The final characterisation of the prototype was done at M24.

✓ Validation at field of the Microdis prototype. Determination of the technical and economical viability for the disinfection of soil → M26; The microwave system was tested using real samples of soil and the soil lifter was tested in real conditions. However, the complete system was not tested at field due a problem with the soil feeding system. This milestone has been achieved partially at M26. However, some technical solutions have been proposed to solve the problem (after the project) with the soil feeding system.

✓ Dissemination and use plan → M26; The completion of an Exploitation Potential & Dissemination and Use Plan. This milestone was achieved at M26.

✓ Guide covering the uses of the developed technology for public dissemination → M26. Preparation of a guide that distils non-confidential elements of the developed technology into a user-friendly form. This milestone was achieved at M26.

✓ Transfer of the developed technology and know-how to the partners organisations → M26. Completion of the transfer of the developed technology and know-how to the partner organisations. This milestone was achieved at M26.

DISSEMINATION AND USE

Since the exploitable results of the project have not been properly covered at the time of writing this report, the *Exploitation Manager* and the Consortium do not consider appropriated delivering this information yet.