PROJECT PRESENTATION

„RESEARCH ON THE DEVELOPMENT OF SOME MATHEMATICAL MODELS TO EVALUATE THE IMPACT OF SOIL CONTAMINATION ON FRUITS AND VEGETABLES”

Project code: PN-III-P4-ID-PCE-2016-0860
The acronym of the project: CONTAMOD
Implementation period: 01/2017 - 12/2019

OBJECTIVE OF THE PROJECT

To achieve the main objective of the project, *the development of some mathematical models to evaluate the impact of soil contamination on fruits and vegetables* to be consumed by the population in large scale, the following ***specific objectives*** are aimed:

O1) Scientific substantiation on the models used worldwide to evaluate the contamination of soil, respectively fruits and vegetables;

O2) Development of theoretical models to evaluate the impact of soil contamination (by heavy metals and other pollutants) on fruits and vegetables. Establishing of work assumptions;

O3) Testing of theoretical models in real conditions based on data obtained from laboratory / field;

O4) Development of mathematical models to evaluate the impact on soil contamination on fruits and vegetables and thus on consumers health;

O5) Wide dissemination of the results and development of proposals for Ph.D themes.

SUMMARY OF THE PROJECT

Environmental pollution is a major problem worldwide, and in this context the European Union adopted in the past 20 years numerous laws, directives and standards for its mitigation, monitoring and if possible, its control.

Soil pollution is a component that contributes to the increase of environmental pollution, as soil is the key element that underpins food production for household consumption. If we refer only to the soil, the level of pollution is given by its degree of contamination with various pollutants, heavy metals, etc.

Because agricultural products in general, respectively fruits and vegetables in this case extract water and nutrients from the soil in order to develop, it is necessary to study how a certain degree of soil contamination (at different depths) leads to the obtaining of some products (vegetables and fruits) which contain a percentage of those toxic elements, that can produce long term sickness and can cause death in people who currently consume such contaminated products.

The research carried out within the project aim to develop some original models *on the correlation between the level of soil contamination, respectively the remanence of polluting substances in fruits and vegetables harvested* for consumption in fresh state and of an optimal method to *reduce / improve / remove / dismantle / control the pollutant substances from the soil*, which will be correlated with a monitoring system of activity and impact of polluting substances / elements in a certain area for rapid improvement actions with neutralizing substances.

PHASES / ACTIVITIES:

Den. No.	Phase / activity name	Objectives	Deadline
P1	**Scientific substantiation of mathematical models used worldwide to assess the impact of soil contamination on fruits and vegetables**	• Scientific substantiation of models used worldwide to assess soil contamination, respectively fruits and vegetables contamination; • Development of theoretical models for assessing the impact of soil contamination (with heavy metals and other pollutants) on fruits and vegetables. Establishment of working hypotheses	**12.2017**
A1.1	Prospective study on mathematical models in the field of soil contamination impact on fruits and vegetables		
A1.2	Establishment of the experimentation methodology		
P2	**Experiments in the laboratory / field. Development of mathematical models**	• Experimentation of theoretical models under real conditions based on laboratory / field data	**12.2018**
A2.1	Experiments under laboratory / field conditions		
A2.2	Development of mathematical models		
P3	**Development of a method for improving parameters to ameliorate soil contamination**	• Development of mathematical models for assessing the impact of soil contamination on fruits and vegetables and, implicitly, on consumer health; • Wide dissemination of results and elaboration of proposals of PhD thesis topics	**12.2019**
P3.1	Experiments in the laboratory / field		
P3.2	Validation of mathematical models		

Results / results presentation documents:

- 7 ISI articles;
- 13 BDI articles;
- 1 European patent application.

Degree of achievement of estimated results:

PHASE 1 - *SCIENTIFIC SUBSTANTIATION OF MATHEMATICAL MODELS USED WORLDWIDE TO ASSESS THE IMPACT OF SOIL CONTAMINATION ON FRUITS AND VEGETABLES*

Activity 1.1. – Prospective study on mathematical models in the field of soil contamination impact on fruits and vegetables

According to [1], some of the substances that form the crust of the Earth are elements, substances that cannot be decomposed into simpler substances. Some of these elements are poisonous, even if they are present in a low concentration. These elements are known as heavy metals. Among the heavy metals, [1] are mercury, cadmium, arsenic, chromium, thallium and lead.

Bioaccumulation [2] is defined as the accumulation of substances (e.g. pesticides) in organisms of various types. Also [2] states that ***bioaccumulation*** occurs in organisms when *absorption* takes place at a faster rate than the *elimination* of the same substances by *catabolism* or *excretion*.

According to [6], *bioconcentration* is a term related to *bioaccumulation*, but more specifically, it refers to the accumulation of a substance only from water. By contrast, bioaccumulation refers to combined absorption from all sources (water, food, air, etc.), [7]. However, the term bioaccumulation has a beneficial sense, as long as it is not associated with substances harmful for certain biological or physical entities. According to [8] or [10], *bioaccumulation* is a process of accumulation, in the soil, of organic substances resulting from the decomposition of vegetal and animal debris that contributes to soil fertilization. [8] also calls *bioaccumulation* the process of accumulation, in the plant, of some substances, which, after decomposition of the plant material, remain in the soil, fertilizing it. Therefore, bioaccumulation is a process of accumulation of substances in a biological entity (soil, plant, animal, etc.). The restrictive meaning of some definitions of *bioaccumulation*, relative to substances that are toxic for living organisms (pesticides, heavy metals, etc.), for example [9], is not recommended because the term may extend to the accumulation of other useful substances and recommends it for studies on living organisms' development within mathematical models.

The mathematical models of heavy metal bioaccumulation are part of the general category of mathematical models describing phenomena in the field of biology. These models are included in that branch of biology called biomathematics, [16] which is the branch of biology that deals with the application of mathematical principles in biology and medicine. Biomathematics has many applications in well-known branches of biology: Comparative Genetics, Population Genetics, Neurobiology, Cytology, Pharmacokinetics, Epidemiology, Oncology, or Biomedicine.

As stated by [18], the progress of scientific understanding in the field of biology and ecology is dependent on the accumulation of factual data, the creation of theories capable of structuring data and explaining phenomena, descriptive modeling of biological realities, and analysis of the findings validity. Although the phenomena of the living (biological) world are based on physicochemical phenomena, says [18], biological phenomena are incomparably more complex than physicochemical phenomena.

[37] states that the classification of mathematical models in biology is heterogeneous, a situation generated by the many possible points of view. The authors [39] give the following classifications:

C1) ***physical*** models and ***abstract*** models;

C2) ***dynamic*** models and ***static*** models;

C3) ***empirical*** models and ***mechanistic*** models;

C4) ***deterministic*** models and ***stochastic*** models;

C5) ***simulation*** models and ***analytical*** models;

Physical models are material models made on a scale that behave similarly to the modelled system. *Abstract* models are built in the human spiritual space and are constructed by systems, components and relations that imitate the functioning of the studied process. *Dynamic* systems are those in which the temporal variable is explicit (simulators based on systems of differential equations and/or partial derivatives). A *static* model is described by parameters and relations in which time does not appear explicitly (for example, regression models such as Fibonacci sequence to simulate changes in the number of rabbit populations). *Empirical* (correlation) models contain empirical relations, do not exhaustively observe the representation of the processes and mechanisms that take place in the real process, and their purpose is to predict and not to explain the causal relations in the phenomenon. *Mechanistic* models aim primarily at describing the internal dynamics of the system and determining the causality of its behaviour by observing the characteristics of its own real system, [37]. *Deterministic* models are characterized by the absence of random variables and lead, under identical initial and loading conditions, to identical predictions. *Stochastic* models include random variables and are more complex than the deterministic ones because, apart from the need to determine constants, it is necessary to determine complete distributions of values assigned to random variables. Generally, by *analytical* methods, [37] understands all methods that are solved using mathematical methods and give analytical solutions. The use of numerical methods or other methods of solving in the model give a *simulative* character to the model, [37].

Bioaccumulation modeling has long spread in the literature on ecological risk estimation [52]. There are a series of studies on the subject of bioaccumulation in invertebrate and small vertebrate species and use statistical models for this purpose [53]. The study of the bioaccumulation phenomenon in sediments or plants appears also in [54] and [55].

In [51], the authors propose a way of evaluating models dedicated to bioaccumulation processes:
- identifying chemicals of interest,
- selecting the factors that influence bioaccumulation potential variation,
- developing the models,
- verifying the viability of the models (validation),
- selecting the best predictions,
- making qualitative and quantitative adjustments,
- selecting key/main predictions or prediction domains and including them for the relevance of the bioaccumulation model.

We can recognize in this way the method of general modeling of processes as systems. In contrast to classical systems in mechanics or those in other classical fields of the art (electromagnetism, thermodynamics, etc.), ecological systems are generally open systems, or systems that cover spatial domains but also temporal domains of very large dimensions. These are specific characteristics of these systems and implicitly the great variability in time and space.

The current trend in modeling bioaccumulation phenomena is to achieve mixed models, which have deterministic components and statistical components. These models are called integrated models. Integrated modeling appears to be absolutely necessary for predicting the transfer of the stable toxic pollutant in a trophic chain that includes organisms characterized by multiple space-time scales. An example of integrated model can be found in [56], and a synthesis of the potential and limits of integrated models in metal biogeochemistry is found in [45].

We further mention some bioaccumulation models for possible consultation when it comes to constructing a mathematical model for bioaccumulation to model a particular phenomenon, concretely. The consultation of these models may tell the researchers if they are on a path already investigated or how far they have moved away from it.

Among the predictive deterministic models (which are difficult to parameterize as they have a complex structure), there are, [37]:

- Simulation of metal bioaccumulation in conifer and deciduous seedlings, using a 32-parameter model describing the concentration of metals in soil and air, metal properties and metal exposure time, take-up rates in different plant tissues and transfer between tissues, metal partition coefficients between the compartments of soil-plant system and aqueous phases, plant growth and metabolism parameters, [61];

- Simulation of metals transport by percolation and soil and their taking over by the plants, [62] - the detailed part from the point of view of the deterministic modeling is at the level of the water transport, the taking over by the plants being very simply modelled by a Michaelis – Mentin equation. The model includes 24 parameters of which 6 characterize the plants.
- Deterministic models of the bioaccumulation of metals are also presented in [47], [49] and [49]. These models simulate the total transport of metals in the plant. The specific application of the model is the simulation of metals phytoextraction from the soil, [49], the simulation results being also relevant for assessing the dynamics of the bioaccumulation process.

Generally, in respect to the deterministic models it can be stated that besides the lack of knowledge about their correct structure for bioaccumulation prediction, an important restriction is the availability of data for parameterization and verification of such models in different types of terrestrial ecosystems, [63].
Statistical models are used to obtain, analyse and interpret data. Statistical models establish relations between variables, without considering the internal mechanisms of processes and without explaining their causality, [64]. The author [65] considers that the statistical models have three important functions:

- They can be tested and verified by real data,
- They can be used to analyse the real data quality when considered abstract and used to describe real phenomena,
- When used for parameter estimation they can suggest emerging properties of the systems or characterize the dynamics of processes and may play a role in resource management.

Also [37] shows that regression models can often be used to determine the form and significance of the relation between two or more variables. We add that, among a certain family of forms one can find, quite often an optimal one, using the method of least squares. Another very tenacious and helpful "assistant" of these operations is dimensional analysis. [66] distinguishes between regressions and correlations: correlations measure the degree of linkage between variables, while regressions also reflect the intensity of the link, but these presuppose a causal relation between variables (one dependent and one or more independent).

In order to choose a model type in case we have to study a concrete process, the authors [40] propose a tabular guide, presented in table 7.

Table 7 - Guide to choosing a mathematical model

Model type	**Characteristics**	**Selection criteria**
Matrix representations	linear relations	valid linear equations, age structure required
Static models	provide an overview in quantitative terms of the situation	applied in situations where there is little data available and quantitative assessments are required while changes correlated with long time intervals are not required
Fuzzy models	provide semi-quantitative results or just indications on rankings	applied in situations where the available data are few and the semi-quantitative results are sufficient
Representations by differential equations	provide space-time variations	require a developed database
Models describing structural dynamics	provide parameter variations as a function of time and/or space based on expert knowledge or purpose of functions	predictions are required in the context of changing conditions and a database developed with changes in properties

Individual-based models	consider different properties of individualities	used where the average of properties/parameters is insufficient

Statistical models for predicting metal concentrations in plants have as main independent variables metal concentrations in the soil. Based on the available analytical data, the concentrations are total or only the bioavailable portion.

The experimental consequences of the mathematical modeling of heavy metal bioaccumulation phenomenon are immediate in the applications for the elaboration of rigorous experimental plans. Thus, the mathematical model and the problems proposed to be solved determine precisely all the parameters to be determined experimentally, as well as the locations in the analyzed system of these measurements (in which component of the system and in which subcomponent: for example in the plant, in leaves, stem, seeds, root, etc.). The complexity of the theoretical-experimental research, in a field where research cannot be conceived without experiment, becomes controllable, and the degree of depth results easily, using estimators resulting from the theoretical-experimental analysis process. Primary experiences will be used both to substantiate the model and validate it. When talking about model substantiation, in the experimental context, we refer to the experimental determination of the model constants. At primary validation, all experimental data will be the subject of experimental validation of the model. The final validation is done on complex loading cases and also partially determines the model limits.

The experimental plan generated by the biodynamic model has as model parameters the rates of contaminant taking over from the environment, k^u and the rate of contaminant elimination in the environment, k^e. Also, the unknown and dependent on contaminant type for the same soil-plant couple is the equilibrium concentration, c_w. Since, ex hypothesi, these two parameters are believed to be constant over time and under established experimental conditions (temperature, pressure, concentration limits, etc.), their value can be determined experimentally from a discharge experiment. Prepare a number of n_{rep} x n_t pots with one plant and the soil contaminated at a known initial value, c_0. The set of *t* indices of the n_t number represents the times at which n_{rep} pots will be sacrificed for the measurements. Consider $\{t_i/i=0,...,N\}$ the sequence of these moments. At each t_i moment n_{rep} pots are sacrificed and the concentration in the plant is measured, as well as the concentration in the soil, considered to be the concentration of the environment. The resultant range of measurements is: $\{(t_i, c_i, cs_i)/i=0,...,N\}$, where cs_i is the concentration of the contaminant in the soil (average value). Then, using the approximation of the derivative by finite differences, we can write the following N-1 equations:

$$(t_{i+1}-t_i)k^u c_w - (t_{i+1}-t_i)k^e c_i = c_{i+1} - c_i \,. \quad (18)$$

From this set of N-1 equations is formed a number of C_{N-1}^3 systems of three nonlinear equations. These nonlinear systems are solved (if possible), obtaining C_{N-1}^3 solutions:: $(k_j^u, k_j^e, c_{w,j})$, j=1,..., C_{N-1}^3. The final solution can be obtained either through mediation or by a statistical study of the distribution of each component of the nonlinear systems solution. For each measurement at the t_i time, n_{rep} soil-potted plant systems are sacrificed, and each triplet of each measurement will have the second and third components (c_i and cs_i) calculated as arithmetic averages of those n_{rep} sacrificed and measured systems. Thus, besides the n_{rep}xN soil - plant systems isolated in separate pots, there must be considered a number of at least 3*N* control plants sacrificed at each t_i time, three of them, which are control systems, without contaminants. Using the control system, it is possible to compare the physiological evolutions of the contaminated plants with the healthy ones. This results in a number N=(n_{rep}+3)N of plant-soil systems in separate pots to be cultivated for experiments. Harvesting (sacrification) times will be established throughout the life of a plant, possibly in a season, in order to harvest the seeds too, so that one could evaluate the presence of the contaminant in the germs of the next generation of plants, eventually on those plants afterwards, the ability to take over other contaminant loads (higher or lower than the parents).

Conclusions

- It is noted, within the limits of the relevant literature consulted, that the models most often used in the study of heavy metals bioaccumulation are the deterministic and the statistical ones.

- Deterministic models are more complete from the theoretical standpoint, cover more parameters, provide causal relations and have a wide range of applicability. The limitations are due to the large number of parameters considered and to the related model constants, which requires a large amount of experimental determinations to identify these coefficients. Costs are not negligible because analyses are as complex as those in the case of statistical models, and, moreover, some of the coefficients are obtained from data by additional calculations, so not directly from analyses. Higher quality experiences require adequate statistical processing.

- Statistical models, in relation to deterministic ones, show a low level of complexity, describing exclusively the experimental conditions for which they were generated (extrapolation is generally risky). Statistical models can be used efficiently in the context of the unavailability of a sufficiently developed data set as well as instruments for monitoring and assisting the decisions associated with risk assessment in certain contaminated areas. The disadvantages of these models are represented by the lack of general character and the inability to provide causal relations for the studied processes.

- Obviously, there is in this case too, as for many other issues, a middle way, namely the use of integrated methods, including both deterministic and statistical models.

- Regarding the existing and public experimental data in Romania, [37] states that the availability is reduced to several series of data characterized by general information (average values, areas of variation, dispersions). With these resources it is impossible to generate statistical models of metals bioaccumulation in crop plants. It is also noted the lack of data georeferencing for the heavy metals pollution problem. As a consequence, it is impossible to properly assess the risk associated with a precise spatial delimitation within agro-systems. In fact, the author [37] notes the large deficiencies of the statistical models built for the Copsa Mica area, especially with regard to the delimitation of areas at risk of exceeding the alert threshold. The results are inconclusive in the correct assessment of the distance from the source at which there is the risk of exceeding the threshold.

- The assessment of the experimental efforts needed to achieve a model of transfer of contaminants containing heavy metals from soil to plants (either a deterministic or a statistical model) shows that the operation is very costly.

- Generally, due to the large volume of literature on the transfer of heavy metals from the marine or terrestrial environment to plants or animals, it is difficult to reach a reasonable threshold of originality. There are some problems that can be studied and can guarantee original and useful solutions, among which:

- *researching the existence of bioaccumulation capacity in plants (in animals or humans), the topic being also related to the threshold of intoxication or illness symptoms occurrence;*
- *researching the mechanisms that can lead to the death of plants (animals or humans) through heavy metal poisoning (and generalization to other chemicals);*
- *the way of transmitting the heavy metal deposit from infected parents to the offsprings, the phytoremediation capacity of infested offsprings;*

Activity 1.2. – ***Establishment of the experimentation methodology***

The activity has as main objective the development of theoretical models for assessing the impact of soil contamination with heavy metals and other pollutants on fruits and vegetables. Establishment of working hypotheses

Through the specific objectives it is desired to carry out some complex researches leading to the development of original models regarding the correlation between the level of soil contamination and the remanence of the polluting substances in the fruits ***(apple, plum, sour cherry, raspberry, strawberry, blueberry, etc.)*** and vegetables ***(spinach, parsley, tomatoes, cucumbers, radishes, etc.)*** harvested for fresh consumption.

When soil conditions allow heavy metals to pass into the soil solution, the increased content of heavy metals in the soil presents a direct risk of soil pollution, of the plants that absorb it, of the humans and animals consuming the respective plants. In addition, heavy metals can be leached into groundwater or surface water and from there to affect humans and animals through drinking water.

The risk of soil and plant pollution depends on:

- plant species,
- chemical form of chemical elements in the soil,
- the presence of other elements, especially those that counteract the effect of metals and substances that counteract the absorption and desorption processes,
- the amount available in soil and soil and climate conditions.

The harmful effects of heavy metals depend on their mobility, their solubility in the soil. Therefore, in the case of soils polluted with heavy metals, the first improvement measures will aim at creating the conditions for the passage of heavy metals from the soil solution in stable forms. In any species, heavy metal concentrations may vary between different parts and organs of the plant, but also with the age of the plant. There are species that have the ability to concentrate at the level of different vegetative organs high concentrations of heavy metals. Therefore, in the polluted areas it is contraindicated the consumption of green vegetables, heavy metals reaching them especially through foliar absorption.

Soil sampling will be made from the two surface horizons because they are considered to be affected by pollution.

Treating soil samples taken for analysis is done according to SR ISO 11464/1998 - Soil Quality. Pre-treatment of samples for physico-chemical analysis. Thus, the samples will be dried in the oven and then ground with a soil electric mill.

Heavy metals to be analyzed: ***Pb, Cu, Zn, etc.***, according to the standard SR ISO 11047/1999 - Soil quality. Determination of cadmium, chromium, cobalt, copper, lead, magnesium, nickel and zinc from soil extracts by flame atomic absorption spectrometry. Metal extraction is done with concentrated sulphuric acid and 50% hydrogen peroxide using a Digestal HACH digestion apparatus.

Copper has a normal content in the soil of 20 mg/kg, an alert threshold for sensitive uses of 100 mg/kg and an intervention threshold of 200 mg/kg.

The determination of pH is made according to SR ISO 10390/1999 - Soil quality. Determination of pH using a pH meter with combination electrode.

The biological material is represented by plants the selection of which was made taking into account criteria such as: frequency of consumption, taxonomy (to represent different families), exposure conditions (surface to volume ratio, growth period), the part of the plant to be consumed (fruits, leaves, etc.), tolerance to diseases and pests and spreading.

For the controlled contamination experiment will be used: *vegetables* ***- lettuce (Lactuca sativa L. var.capitata), spinach (Spinacia oleracea), parsley (Petroselinum spp.)*** cultivated as leafy vegetables, **carrot (*Daucus carota*)**, **European radish** (***Raphanus sativus convar sativus***) cultivated as root vegetables, **cucumber (*Cucumis sativus*)** and **tomato** (***Solanum lycopersicum***) and *fruits* ***(apple – Malus spp.; plum – Prunus domestica; sour cherry - Prunus cerasus),*** but also *berries* (**strawberries**

- ***Fragaria spp.; blueberries - Vaccinium myrtillus; raspberries - Rubus idaeus; blackcurrants – Ribes nigrum***) because:

- they are some of the most consumed vegetables and fruits, rich in nutrients;
- they are usually consumed as such, raw;
- among vegetables, they have the highest accumulation capacity of heavy metals, without the manifestation of phytotoxicity visible symptoms;
- the selected vegetables have a short life cycle and develop well under controlled environment conditions (greenhouses, solariums). The locations with the experimental plots are to be established later (greenhouse and field).

Working methods and equipment used:

- *Atomic absorption spectrophotometry*
- *Inductively coupled plasma optical emission spectrophotometry*
- *High-performance liquid chromatography*

Parameters of the soil-plant system in laboratory experiments (tab.1) consider:

- establishing working hypotheses to facilitate the development of experiments for building and applying mathematical models of the soil-plant system;
- the experiments to be carried out will be opened in the sense that parameters can be added or removed depending on the results obtained during their deployment;
- the source of calculating the number of experiments taking into account the life cycle of plants within the experiments;
- starting with 2 kinds of crops: vegetables from the group of leafy vegetables (lettuce, spinach, parsley, etc.) and then with fruit trees (apple, plum, etc.).

Table 1 - Parameters of the soil-plant system in laboratory experiments

No.	Parameter name	Notation	Unit of measurement	Number of variants
1	Plant type	P_i	-	***Vegetables -*** lettuce, spinach, parsley ***Fruits*** – apple, plum
2	Contaminant type	C_i	-	**Pb, Cu, Zn**
3	Crop type	Tc_i	-	2
4	Soil type			
4	The amount of soil in the pots / soil area allocated to field experiments	V_{ssa}	m^3	-
5	The function of concentration variation of the contaminant in the soil	c_s	-	-
6	The function of concentration variation of the contaminant in the plant root	c_{cr}	-	-
7	The function of concentration variation of the contaminant in the plant stem	c_{ct}	-	-
8	The function of concentration variation of the contaminant in the plant leaves	c_{cf}	-	-
9	The function of concentration variation of the contaminant in the plant seeds	c_{cs}	-	-
10	Number of measurements per plant life cycle	n_{mcv}	-	-

Types of contaminant loads (Pb, Cu, Zn)

Contaminant (Pb, Cu, Zn) loads, by their mode of administration, can be done in two ways:

- loading directly into the soil with contaminant solution on controlled depth, in relation to the seedling planting depth (the ratio between the application depth and the planting depth/the length of the seedling root can take an infinite number of values)

- contaminant loading by rain;
- air loading with contaminant content, but it is difficult to control it and there is the risk of environmental pollution.

In terms of time evolution, contaminant loads can be of the following types:

- zero load – characteristic of the control soil-plant system, free of contaminant (mandatory load in order to achieve the reference)
- initial load - non-zero at the initial moment, mandatory, which models a contamination isolated over time;
- periodic load - which models periodic loads (produced by industrial sources or other sources);
- progressive load over the entire life-cycle – monitors the eventual decrease of the plant life time and death during its vegetation period;
- other forms of load required by experiments deployment.

PHASE 2 - *EXPERIMENTS IN THE LABORATORY / FIELD. DEVELOPMENT OF MATHEMATICAL MODELS*
Activity 2.1. – Experiments under laboratory / field conditions
Activity 2.2. – Development of mathematical models

PHASE 3 - DEVELOPMENT OF A METHOD FOR IMPROVING PARAMETERS TO AMELIORATE SOIL CONTAMINATION
Activity 3.1. – Experiments in the laboratory / field
Activity 3.2. – Validation of mathematical models

ARTICLES PUBLISHED IN ISI REVIEWS / CONFERENCES:

1. Despina-Maria Bordean, Vladut Nicolae Valentin, Ioan Caba, Ioan Gogoasa, Liana Alda , Camelia Moldovan, Diana Moigradean, Luminita Pirvulescu, *Mathematical and chemometrical models – tools to evaluate heavy metals contamination,* Scientific Papers: Animal Science and Biotechnologies, 2017, 50 (2), pp. 162-167, ISSN online 2344 – 4576.

2. Despina-Maria Bordean, Nicolae-Valentin Vladut, Ioan Caba, Luminita Pirvulescu, Diana Nicoleta Raba, *Magnesium - an ancient mineral and the today's deficiency,* PROCEEDINGS OF THE 18th International Multidisciplinary Scientific GeoConference SGEM 2-8 july 2018, volume 18, Issue: 5.1, Ecology, Economics, Education and Legislation, Albena, Bulgaria, ISSN 1314-2704.

3. Pruteanu A., Bordean D.M., Voicea I., Vlăduț V., Găgeanu I., *Experimental researches concerning heavy metals contamination (Cu, Zn, Pb) in leafy vegetables,* PROCEEDINGS OF THE 18th International Multidisciplinary Scientific GeoConference SGEM 2-8 july 2018, volume 18, Ecology, Issue: 5.1, Economics, Education and Legislation, Albena, Bulgaria, pp. 385-392, (DOI:10.5593/sgem2018/5.1).

4. Petru Cardei, Catalina Tudora, *Theoretical research on evolution of health of plants affected by heavy metal absorption process***,** Engineering for Rural Development, Jelgava, 23.-25.05.2018, pp. 893-897, DOI: 10.22616/ERDev2018.17.N186.

POSTERS:

1. Pruteanu A., Vlăduț V., Nițu M., Voicea I., Bordean D., *Contaminarea controlata a solului cu metale grele si remanenta acestora in spanac*, 7th International Conference on Thermal Equipment, Renewable Energy and Rural Development 2018 TE-RE-RD.