PHYTOREMEDIATION TECHNOLOGY: QUANTITATIVE ASPECTS OF FURTHER DEVELOPMENT

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Abstract

Dynamic and quantitative peculiarities of soil phytoremediation have been investigated by means of mathematic models of radionuclide migration into system " soil-one year plant", "soil- many years' crops". Possibile efficiency of phytoremediation technology has been estimated .It is calculated that only increase of annual pollutants release to 2-3% permit to avoid of delay of pollutant into topsoil during the first 8-10 years after fallout

Introduction

The main principles of the phytoremediation were developed in the late 1980s and early 1990s

It uses highly-cumulative plant species to collect, accumulate and extract (removal) of the pollutants from soil by plants biomass. Phytoremediation has been proved to be useful for radionuclides, heavy metals or organic contaminated sites. If we take into consideration natural interconnection of soil and plant, application of phytoremediation has plenty advantages. Transpiration flow of a growing plant can create vertical and horizontal stream of soluble mineral elements. This stream is nearly 10-100 times higher than the rate of diffuse migration and can provide regular removal and collection of mineral pollution from soil of the upper layer. In addition, root excretion and metabolites of soil microorganisms can increase the rate of destruction and solubilize some solid contaminants, thus enhance uptake of heavy metal and radionuclides from solid matrix. It has been demonstrated that phytoremediation is most inexpensive clean-up method, more than 5-6 times cheaper than the other methods. Today, there are several directions of this biotechnology development and improvement [review, 4]:

1. Search of the plants with high index of accumulation and high biomass
2. Use of soil amendments to increase bioavailability of pollutants

Chelating agents (e.g., EDTA) are used to increase bioavailability of metals in soil []. At present it is known that EDTA and FDTA have toxic effect for soil biota . Furthermore, these chemicals are expensive and are not realistic for large territories. Cost of these amendments is 70% from cost of project

3. Obtain and use transgenic high-cumulative plant

Transgenic plant is plant with modification of genome as a result of transfer some outside gene or genes. This is a very expensive technological way. Today transgenic plants give promotion of pollutant accumulation only by 2-2.5 times.

4.Use of the physiological methods to enhance plant accumulation ability of abiogenic elements such as radionuclides and heavy metals [2-4].

It is demonstrated that use of some simple and available approaches such as high density of sowing, high level of watering, can lead to increased level of root excretions, biological availability of radionuclides and cation exchange capacity (CEC) of plant biomass . As a result, the accumulation level of radionuclide can be increased 2-2.8 times [2,3]. Preliminary results demonstrated that use of physiological method could increase radionuclide accumulation and phytoextraction of ^{90}Sr to 4-5% a year.

Development of any technology must be grounded on the quantitative estimation of its efficiency. Migration of mineral pollution in the system soil-plant is a complex and unstable process including plenty interaction of soil, climatic and physiological factors. Calculation of efficiency may be based on quantitative estimation of kinetic peculiarity of pollution migration and its following interaction with the main factors - climatic, soil and biotic, its transformation and involvement into biological circulation.

The purpose of our present investigation is the estimation on the base of numerical modelling of the possibilities of physiological control of the pollutant accumulation and release with plant biomass.

<u>The General Scheme of Calculations</u>

Numerical estimation and calculation of rate of soil natural clean up has been realized within two module models: migration of radionuclide in soil without sowing and migration of radionuclide in systems "soil-one year plant", " "soil- many years' crops".

1.The first module: Estimation of the relative rates of soil cleans up with physical migration.

The first model is one dimensional transport equation describing the migration of radionuclide in soil as porous solid matrix united with the equations describing the alteration of solubility of pollutants. The main mechanisms of these processes, namely: natural decay of radionuclides, infiltration, diffusion, destruction of "solid" forms of radionuclides ("hot" particles+ radionuclides fixed in soil minerals), and insertion of ^{137}Cs into crystal lattice of soil minerals have been registrated.

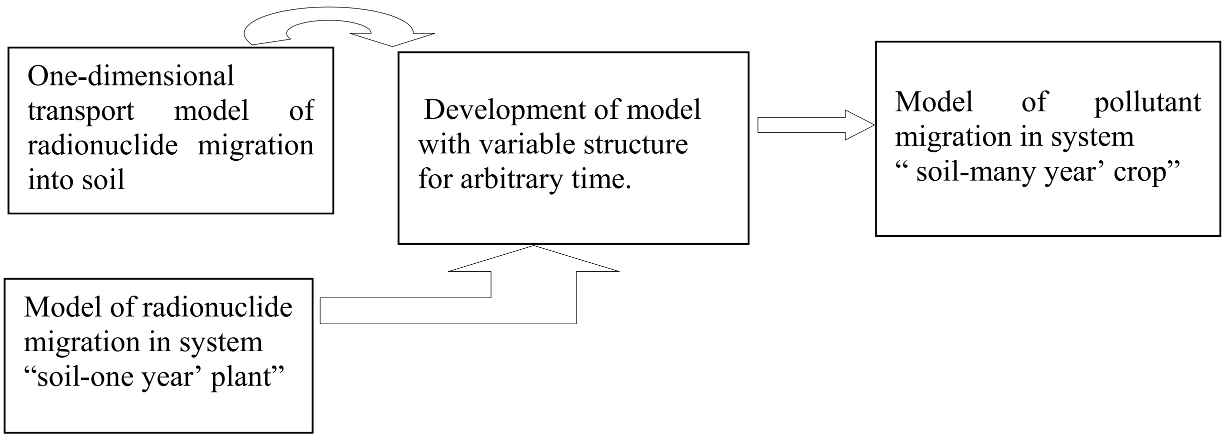


Fig 1The General Scheme of Models to calculate Efficiency of Phytoremadiation Technology Interaction

$\partial A_m/\partial t = D/R\ \partial A_m^2 (t) / \partial^2 x - V/R\ \partial A_m(t)/\partial x + K_{hm} A_h(t) + K_{cm} A_c(t) -$

$- \lambda A_m(t) - \beta A_m(t)$

$dA_h/dt = -(K_{hm} + \lambda) A_s(t)$ (1)

$dA_c/dt = \beta A_m(t) - (K_{cm} + \lambda) A_s(t)$

$A_s(t) = A_c(t) + A_h(t)$

where A_m – partial radioactivity of soil solution; A_s –fix forms of the pollution, $A_h(t)$- 'hot" particles, $A_c(t)$- fixed of the soil mineral ; λ - index of radioactive decay; K_{hm} – rate of "hot" particle destruction; K_{cm}- rate of destruction solid form of pollutant fixed by soil mineral; β - rate of ^{137}Cs insertion into crystal lattice; D= D/R – actual rate of diffusion, V- actual rate of infiltration, $R = 1 + \rho K_d/Q$ - the retardation factor, accounted for the slower movement of radionuclide due to matrix sorption than the water, K_d – index of radionuclide distribution between fix and soluble form ; Q- moisture content of the bulk soil; ρ - partial density of dry soil.

The chemical methods of division of non-exchange radionuclide forms into fuel particles and fixed into crystal lattice of soil mineral are absent . At the same time data which indicate identity of behavior of the fuel and soil particles with fixed radionuclide has been obtained .

These facts permit to unite states (compartments) $A_c(t)$ and $A_h(t)$ into compartment of non-exchange forms $A_s(t)$ and to turn to more simple model as follows:

$$\partial A_m/\partial t = D/R\ \partial A_m^2 (t)/\partial^2 x - V/R\ \ \partial A_m(t)/\partial x + K_{sm} As(t) - \lambda A_m(t) - \beta A_m(t)$$

$$dA_s/dt = \beta Am(t) - (K_{sm} + \lambda)\ A_s(t) \qquad (2)$$

In this case we can use unified parameter of relative rate for both desorption of pollutant fixed by soil minerals and destruction of fuel particles, i.e. $K_{hm} = K_{cm} = K_{sm}$.

The second module. Model of radionuclide migration in system soil-plant

The formal model describing of pollutants migration within sistem "soil- one year plant" and taking as a basis main principles of this complex procesis, such as:

1.Absorption and accumulation of the pollution is indissoluble connected with plant growth and biomass production. Plant growth is production of new sites of mineral element binding, change of cation exchange capacity of vegetable tissues, requirements and degree of the plant provision with the functional significant mineral elements.

2.Plant absorb dissolved part of mineral pollution only.

3. There is close functional connection between transpiration and biomass production.

4.Plant have non specific ability to control of the chemical mobility and biological availability of any mineral elements (radionuclides and heavy metal, including.

5.Removal of the mobilemineral elements (such as Cs, K *etc*) from plant is reaction of the first order.

The system of model equations [1] describing these principles is as follows:

$$dA_p (t)/dt = T/R\ dM (t)\backslash dt\ \ \alpha\ A_m(t) - [1/ M (t)M(t)\backslash dt + \gamma]\ A_p(t)$$

$$\partial A_m/\partial t = D/R\ \partial A_m^2 / \partial^2 x - V/R\ \partial A_m/ \partial x + K_{sm} As (t,x) - (\beta+\lambda)\ A_m (t) - M(t)A_m (t)/Q\ h (x, t)\ S(t);$$

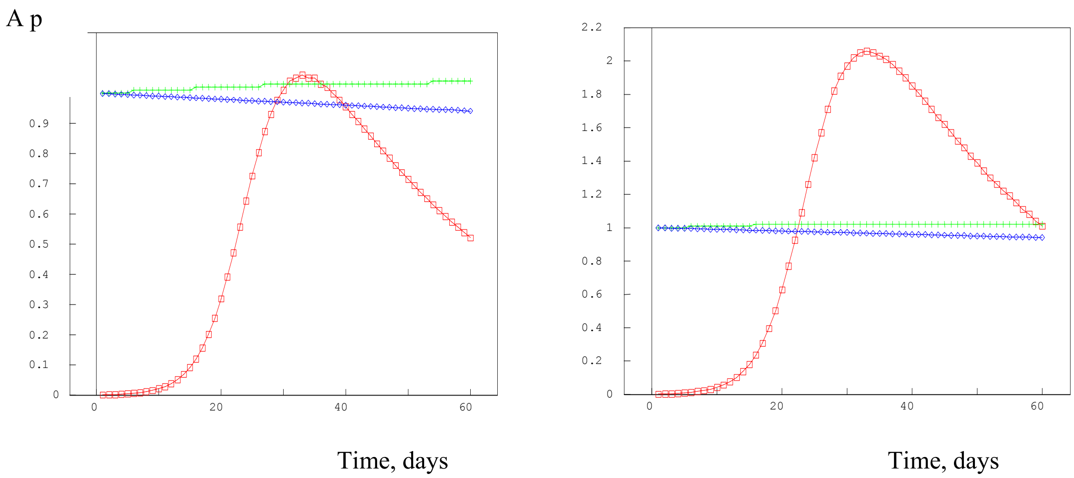
$$dA_s / dt = - (K_{sm} - \beta + \lambda)\ As (t);$$

Where-A_p(t)-partial radioactivity of dry plants biomass, M (t)-function of dry biomass production , α index of provision of mineral elements; T-transpiration index is intervol from 250 to 500 , h*S-area of root spread; S^{-1} - density of sowing, γ - rate of removal of radionuclides from plant biomass.

The third step of our calculation consists in the united decision of systems (2 and 3) for any succession of months and years.This approach considers pollutant migration in systems soil-plant as a process of variable structure and takes into account alteration periods of plant vegetation and its absence (Fig 1).

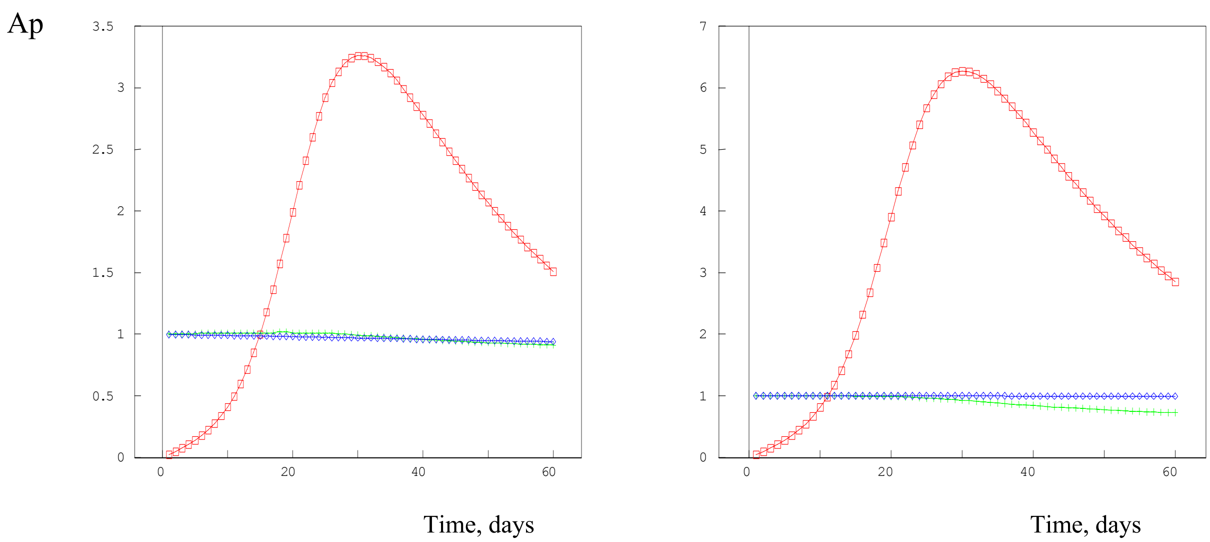
<u>Results.</u>

Thus proposed models permit to carry out diverse estimations of influence of physical, chemical and physiological factors on accumulation of pollutants by a plant. The models take into account:



A B

Fig 2 Model calculation of ^{137}Cs migration in system "soil-one year' plant"A- 60% from total moisture capacity, B – 100% from total moisture capacity



A B

Fig 3 Model calculation of ^{137}Cs migration in system "soil-one year' plant"A- 1000 p/m^2, B-2000p/m^2

□-partial activity (A_p, kBq/kg) of plant biomass; ◊- A_p of soil solution, *-A_p of plllutant' solid fraction growth of plant biomass, transpiration, cation exchange capacity (CEC) of plant tissues, level of provision of biogenic elements, natural decay of radionuclide, infiltration, diffusion, destruction of "solid" forms of radionuclide in soil ("hot" particles+ radionuclide fixed in soil minerals), biogeochemical type of behavior of pollutants in general.

The solutions of the first modul of model demonstrated that values of half-time of natural soil clean-up are situated in interval from 26 to 29.5 years for ^{137}Cs and from 23.3 to 27 for ^{90}Sr.

Some results of numerical decision of the second module of proposed model (eq.3) have been shown in fig 2 3 (positions A-B). Influence of different level of soil moisture (60 and 100% of whole moisture capacity) and densities of sowing upon level of Cs accumulation have been demonstrated. Results of these solutions are evidence of their high dynamic and quantitative correspondence to experimental results and observations [3].

The decisions of united model that is system with variable structure (alteration system of eq.2 and 3) have been obtained and testified on the significant dynamic complication of the migration process. All these curves have visible tooth-like projections and some curves have shoulder. One "tooth" of these curves reflects radionuclide removals from soil solution during one vegetate period. The shoulder reflect retention of a pollutant into upper soil layer due to plant root sucking action caused by transpiration The results of model decisions for two scenarious analyzed above are shown in fig 4

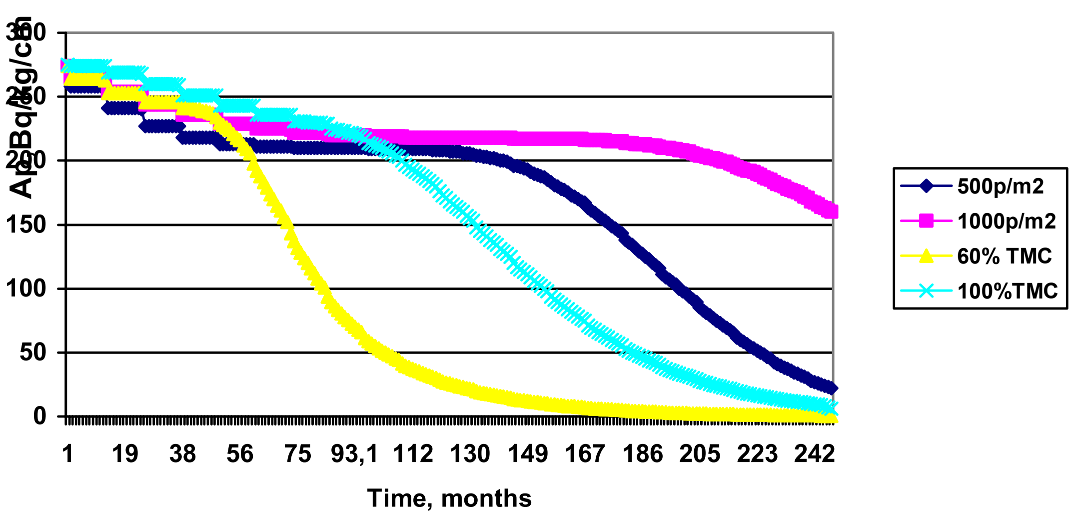


Fig 4. Theoretical calculation of ^{90}Sr migration in system "soil-many year' crop" for two forms o f physiological pollutant accumulation and release control.

Different high of “teeth” is a reflection of different density of plant sowing and level of soil moisture. It is calculated that only increase of annual pollutant moving away with plant biomass to 2-3% would permit to avoid retention of pollutants in top layer of soil during the first 8-10 years after fallout.

Models have wide additional practical utilization. They were used as submodels in three-modul model for assessment and prognosis of radiolodical results of pollution of agrosenosese of Ukraine, estimation of efficiency of phytoremediation and pathways of optimization of this process.

Due to the generalized structure of the models they may be used for optimization of accumulation of any mineral elements, including biogenic (fertilizer) and long-term balance estimations in case if appropriate parametrization is conducted.

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