Int. Agrophysics, 1998, 12, 25-32

ROLE OF AGROPHYSICS IN THE CONCEPT OF SUSTAINABLE AGRICULTURE

J. Gliński, R.T. Walczak

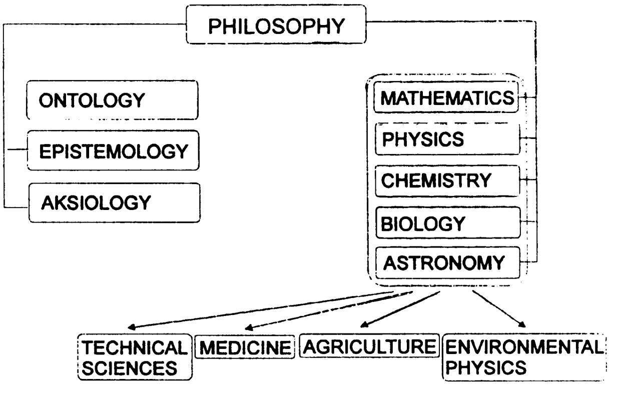
Institute of Agrophysics, Polish Academy of Sciences, Doświadczalna 4, P.O.Box 201,
20-290 Lublin 27, Poland, E-mail: rwalczak@demeter.ipan.lublin.pl

A b s t r a c t. Agrophysics, which is a part of enviromental physics deals with physical and physicomechanical processes connected with mass and energy exchange in soil-plant-atmosphere system and the processes related to gathering, transport and storage of agricultural plant materials. The development of modern sustainable and safe biological production without the knowledge of agrophysical factors is not possible.

K e y w o r d s: agrophysics, sustainable agriculture

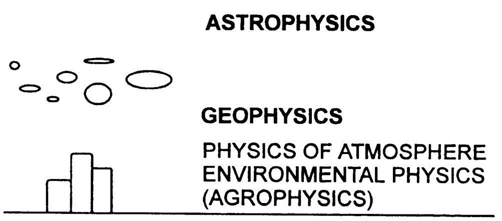
In the first stage of the development of science understood as philosophy, took place the creation of new branches. In this process, the pure philosophical divisions appeared such as ontology, epistemology and aksiology as well as nature sciences as mathematics, physics, biology and astronomy etc.

Natural sciences were the subject of further divisions, for example chemistry, technical sciences, medical sciences, agriculture, etc. During their development, these new branches created questions and using specific methodology found the answers. These answers lead to formulation of new ones more sophisticated and this is the mechanism of knowledge development. It is inevitable, that in a certain stage of its development, a discipline of knowledge is unable only by itself to answer all arousing questions. In this situation, it is necessary to incorporate the methods and experiences of others disciplines, what leads to creation of new interdiscipline branches of knowledge. This process was especially evident



from the middle of this century. The examples of such interdiscipline sciences can be biophysics, biocybernetics, nuclear medicine, genetics engineery, etc.

Examples of application of physics in the development of knowledge in other branches of natural sciences are: astrophysics, physics of atmosphere, environmental physics and geophysics.



The development of environmental physics is very important for mankind due to its relevance to a direct description and modelling and prediction of human environment.

Agrophysics is an integral part of environmental physics and it deals with the processes in agricultural used lands and processes connected with food production. Such areas cover only 9.7 % of global Earth surface however they are under intensive human ingeration, e.g., monoculture crops, water management and high level of chemical and mechanical treatment.

Agrophysics, which is a part of physics of environment, is occupied in investigating of physical and physico-chemical processes connected with mass and energy exchange in soil-plant-atmosphere system and the processes related to gathering, transport and storage of agricultural plant materials [1,2]. The main feature of these studies is the application of physics in agriculture investigations together with its specific scientific methods of reasoning, analysis and interpretation. In agrophysics, like in other natural sciences, the fundamental method of description of investigated objects and physical phenomena and processes taking place in them is modelling.

Knowledge of physical properties of the soil-plant-atmosphere-system and their time and space variability allows physical model development for simulation and prognosis of evolution of environmental conditions in time [5,6,11,16,18,21,22,25-28,30,32-34,36].

Developed models make possible to prognoses the human environment change due to global climate change and human activity (land use, food production, etc.). These models are applied to perform actions against degradation of natural environment.

We understand model as a set of assumptions simplifying the description of a physical object of interest, process or phenomena, engaging the most important properties of this object and presenting it in a way that an object, process or phenomena which in general does not exist in reality, has the properties sufficiently similar to the real object.

According to the way of description of processes taking place in the investigated models the models can be divided into the following groups: real models, analogue models, theoretical-mathematical-physical models and phenomenological models.

The real models concern field or laboratory experiments. An experimental site is a model of crop field in decreased scale. Performing field experiments in controlled conditions (e.g., controlled level of fertilisation and watering) also has a character of model investigation. Lysimetric and pot studies are also the examples of the real model investigations. The real model can be a greenhouse. It makes it possible to perform investigations in precisely controlled fertilising, water management and microclimatic conditions.

A large number of laboratory investigations are performed on miniaturised objects (models). The example can be the soil column with installed sensors for soil water content and potential measurement.

The analogue models which were spread in the period proceeding the development of microprocessors enable the description of a given object, phenomena or physical process with help of other analogical object, phenomena or physical process. The analogue models are created to simulate slow real processes, e.g., the flow and accumulation of water in porous medium can have an analogue in flow and accumulation in resistances and condensers net. In the method of oxygen diffusion rate measurement in the soil, the physiological process of consumption by roots is analogised by electrochemical process of reduction on platinum electrode.

The development of numerical methods and computerisation made it possible to construct theoretical-mathematical-physical models enable simulation of real processes taking place in soil-plant-atmosphere system. In every theoretical model of physical processes three elements occur: mathematical theory understood as the set of constitutional equations, calculation methods of physics as well as calibration and verification experiment. Solving these equations analytically or numerically its possible to predict spatial and time variability of a chosen physical parameter for a given initial and boundary condition.

The example of such solution is a model of water movement in soil profile where by solving Richard's equation with taking into account preferential water flow we can predict moisture variability in soil profile in time, for a given soil and plant cover characteristics as well as for various climatic conditions (EURO-ACCESS) [8].

The fundamental principles, which should be fulfilled by such a model are the mass and energy conservation principles for a system expressed by the continuity equations with the possibility of including the source function. The source function describes positive or negative source expressing wetting or drying water drainage systems or water consuming root system as a negative source of water. The intensity of this source depends on the stage of growth of the rooting system, phenological development of plants and agroclimatic condition.

Phenomenological models are constructed when a real process is too complicated for detail physical-mathematical description. Such processes are evapotranspiration, erosion, biomass production. Models of these processes consist of theoretical mathematical-physical equations as well as empirical parameters. Such models need calibration for the conditions of modelling: kind of plant cover, soil and topography characteristics and agroclimatic conditions.

In order to presented models can serve its purpose it is necessary to equip these models with indispensable input parameters and characteristics. The most important are water and heat soil characteristics and parameters.

Soil water characteristics (e.g., soil water retention curve, saturated and unsaturated hydraulic conductivity coefficient, diffusivity coefficient) are most important input parameters for the hydrological submodels of crop growth prediction models. These characteristics can be estimated using easily measurement soil parameters as: bulk density and porosity, pore size distribution, particle size distribution, organic mater, specific surface area or can be determined using monitoring systems for moisture, water potential, temperature and salinity.

Metrology engaged with theoretical problems connected with measurements planing and realising as well as with practical problems of measurements, conversion of measurement signals and problems of measurement systems [29,31]. Agrophysical metrology is the part of metrology engaged with problems of measurements of agriculture object properties and as well as parameters of physical and physical-chemical processes in soil-plant-atmosphere system. In order to serve in practice to realise measurement device is necessary to correctly define measurement parameter, process or object, elaborate the method of measurement and get through analysis of results[15,23].

A specific feature of agrophysical objects is their variety: soil-plant-atmosphere system, capillary-colloidal-porous bodies, bodies built of cells and tissues. It should be pointed out that these objects show high variability in time and space and are biologically active.

Characteristic feature of soil properties as well as parameters of plant development environment is their time and space variability. Therefore in agrophysics, geostatistical methods are applicable for data collection, analysis and interpretation.

By analysing the variability of a given parameter and the trends of its values changes, it is possible to estimate the values of this parameter in a chosen point of time and space, as well as performing representative agrophysical observations with defined localisation, time and space step of sampling and the number of repetitions.

The progress in agricultural production is a consequence of the development of agricultural sciences. These natural sciences, being interdisciplinary, need various 'pure' disciplines, mainly biology, chemistry and physics, in order to investigate agricultural materials, such as soils, cultivated plants and plant materials.

The progress in plant production during the last decades took place as a result of the use of agrochemical for soil fertility and pest control and achievements in plant breeding. Yield increase was also a result of improved planting and harvesting equipment, and irrigation.

The danger of the aggravating effect of excessive amounts of chemicals on the quality of consumption products and on the environment has appeared.

Recently there has also been considerable progress in the mechanisation of agriculture reflected by an increase in the number of machines which, through their traffic upon the soil and its cultivation, cause changes in the physical status of the soil, often in the direction of properties unfavourable to the growth of plants and additionally degrading environment [7.19,20].

Soil, as plant environment, is relatively little known in regard to physical properties and their influence on the quantity and quality of crops. On the other hand, growth of plant production comprising the increase of farm machines, results in significant changes of soil physical properties. These changes may, in certain conditions limit the efficiency of the applied measures and also develop intensive processes of soil degradation through soil compaction and erosion.

Also knowledge concerning the physical properties of plants, plant materials and plant products is not yet satisfactory. We can be proud of great achievement in increasing crop yields. This increase, however, is not fully utilised due to a lack of knowledge of plant quality features, and particularly of their physical properties. Protection against quantitative and qualitative losses of the mass of agricultural plant materials produced is then, one of the most important economical problems.

In this situation the knowledge of the physical properties both the environment of plant growth and of plant materials as well as physical processes in these objects appear to be an important factor in the sustainable agriculture [24].

Agrophysics is an application of physics to agricultural materials and is a basis for the knowledge of chemical and biological transformations in soil environment and also of agricultural technological processes. Agrophysical investigations through the application of physics and physicochemistry to agriculture are focused on increasing the efficiency of plant production, decreasing soil degradation, improving water quality and lowering quantitative and qualitative losses of plant materials.

The basic agrophysical problems are solved by investigations carried out on:

- Hydrothermophysics
- Mechanics
- Aeration and gas exchange
- Physical chemistry.

The **hydrothermophysics** deals with:

- Water and thermal properties of elements of the soil-plant-atmosphere system and agricultural plant materials.
- Modelling of the water, salt and energy exchange in the soil-plant-atmosphere system.
- Agrophysical metrology.

The knowledge of the connection between measured soil parameters and properties influencing transport processes in the soil is a crucial issue to develop methods and agrotechnical advise to modify parameters in order to gain more desirable properties.

The chemicals concentration, migration and decay which determine the environment degradation and its protection are investigated as strongly influenced by water and heat transport properties.

Knowledge of physical properties of the soil-plant-atmosphere system and their time and space variability allows for physical model development for simulation and prognosis of evolution of environmental conditions.

Physical and mathematical models of water and salt transport in the soil are included into the models of the plant growth and crop yield. The most difficult is problem of preferential (by-pass) flow in soil.

The main feature of the measuring detectors is the device, which makes it possible to transform any measured physical value into electrical signal. This signal can be easily sent, transformed and recorded. The analogue electrical value is most frequently transformed into the digital form and can be easily sent, transformed and recorded in the computer memory. The first step in the computer processing is the transformation of a digital signal into the measured physical value with the use of an algorithm describing the dependence between the measured physical value and the value of electrical signal.

The use of computer as a processing unit, controlling measuring system, makes it possible to choose the measuring detector by addressing and utilising of an appropriate transforming algorithm. The frequency of measurement can be realised according to the constant or changing time step, determined, on line from the analysis of the variability of particular measured parameters.

The analysis of these physical values makes it possible to: identify time-space distribution, correlation and trend changes of chosen parameters, verification of the mathematical-physical models, control of performing devices (e.g., the irrigation system, the elements of laboratory equipment controlling the boundary conditions, etc.).

An example of modern solution of agrophysical metrology is the method and equipment for soil water content measurement using time domain reflectometry (TDR) [12-14,35]. This method is based on the measurement of the velocity of electromagnetic pulse propagation in the investigated medium. This velocity depends on the dielectric constant of the medium. The water content considerably modifies the dielectric constant of the soil and therefore it has an impact on the velocity of electromagnetic wave propagation in it. The elaborated device enables the measurement of the moisture, electrical bulk conductivity and temperature simultaneously.

The knowledge of bulk electrical conductivity and electrical permitivity makes it possible to determine soil salinity by calculation of salinity index value. The laboratory version of the reflectometric meter of soil water content, additionally equipped with the detectors for the measurement the soil water potential enables to determine the soil water retention curve and the water transport characteristics in the soil. These soil characteristics are the parameters used in the hydrological models describing water and salt movement in the soil-plant-atmosphere system.

For big using in agriculture areas the analysis of thermovision images can be used for the investigations of plant water stress and for actual evapotranspiration estimation. The results of these investigations can be applied for the interpretation of air- borne and satellite images.

The investigations on **mechanics** are concentrated on:

- Qualitative description of structural changes of agricultural materials, using statistical distributions, obtained experimentally.
- Integration of probabilistic equations formulated for structural elements (grains, pores, aggregates, cells, cell walls, fibbers).
- Non-destructive methods of analysis of agricultural materials (optical and electron scanning microscopy, computer tomography, acoustic emission and computer image analysis).

Soil **aeration** investigations comprise biological processes of absorption (O_2, CH_4, N_2O) and production (CO_2, CH_4, N_2O, C_2H_4) of gases in soil medium, physical processes of gas transport and exchange between the soil and the atmosphere as well as the effects of particular components of the soil atmosphere on soil processes and on the plants [4].

In details aeration research are directed to the studies of:

- Physical determinants of the soil aeration status such as soil structure (bulk density, aggregation) and soil water content and their influence on gas diffusion coefficient, distribution of oxygen concentration and redox potential in soil.
- Effect of soil redox conditions on biochemical processes occurring in the soil denitrification, reduction of Mn and Fe, activity of soil enzymes, biomass production, nutrient uptake, stomatal diffusive resistances, superoxide dismutase activity, malondialdehyde level and pigment content in plants.
- The notion of aeration concerns also the problems of gas absorption production and transport during storage of agricultural plant materials as well as the effects of the composition of the atmosphere on the storage process itself.

The main topics of the **physical chemistry** of agricultural materials are:

Influence of the modification of soil solid phase by various agents (organic matter, sesquioxides, pollutants) on soil surface properties.

- Water vapour adsorption on soils: estimation of adsorption energy distribution functions using different theoretical models.
- Ion exchange in soils: soil acidity, cations and anions adsorption.
- Influence of the environmental factors on the change of surface properties of roots.
- Soil fractals.
- Physicochemical methods of reclamation and purification of saline, heavy metals polluted and acidic soils.

As a consequence of the fundamental agrophysical investigations are those concerning:

-Soil physical conditions and root growth and function [3].

-Impact of degradation processes on land quality in agroecosystems.

-Relationships between soil physical factors and microorganisms activity.

In the field of the **physical properties of plant materials** for their evaluation and improvement important role play [17]:

- Mechanical properties of plant granular solids which are of great importance in all phases of their technology (storage, handling and processing) to achieve the desired control.
- Qualitative evaluation of fruits and vegetables to decrease their losses especially due to poor post harvest grading and handling.
- Advantage of physical properties of cereal grains for evaluation their utility values.

One of the examples of the special role of agrophysics in the sustainable agriculture might be the last results of the investigations carried out within the international multilateral projects on: (1) the role of soil structure functions for the agricultural biomass production and soil protection and (2) construction of physical models for plant yields and especially soil hydrophysical model to predict the effects of climate change on land use within the European Community EURO-ACCESS [9,10].

It is also a great achievement of indicating the role of redox processes in transformation of ecologically harmful chemicals in soils towards polluting surface and subsurface waters and air. Of a special importance is possibility to estimate ecological damages connected with nitrogen losses due to denitrification and increase of nitrous suboxide emission (strong glasshouse gas) to atmosphere.

Harmful redox conditions can be a trigger for mobilisation of chemicals stored in soils and sediments in the aspect of so called chemical time bomb (CTB).

Assuming that agriculture is one of the significant pollutant source of agrochemicals and factor of physical soil degradation, better knowledge of physical properties and processes in soil environment may require less agrochemicals, and decreasing the potential for ground and surface water quality degradation. In addition decreasing of quantitative and qualitative losses of plant materials on the basis of the knowledge of their physical properties and technological processes are significant share of agrophysics in agriculture for XXI century. One of the main elements of the trend on L.I.S.A (Low Input Sustainable Agriculture) are protection of the agricultural environment and product quality.

For the future development of agrophysics are proposed some priority problems:

- Theoretical and experimental investigations for a new, uniform mechanics of multiphase agricultural materials (soils, grains, plant organs and cells) with the recognition and quantitative description of such physical features of a medium which decide about its susceptibility to destructive action of external factors and especially strains.
- Model investigations of physical and physicochemical processes in soil-plant- atmosphere continuum in conditions of sustainable agriculture and especially elaboration of methodical bases necessary to their prognosis and regulation to optimise conditions of root development and plant growth and yield of high quality.
- Methodical works on measurements and monitoring of physical properties of soil and plant media, recognition their influence on physical processes in agricultural systems and use to evaluation of soil environment of cultivated field, quality of plant materials and products.

It is also needed exclusion of agrophysics, as a separate discipline from agricultural sciences and to introduce it wider to educational university programmes.

REFERENCES

1. **Gliński J.:** The need of soil physical research. Folia Soc. Sci. Lublinensis, Geogr., 1, 30, 5-14, 1990.
2. **Gliński J.:** Agrophysics in modern agriculture. Int. Agrophysics, 6, 1-7, 1992.
3. **Gliński J., Lipiec J.:** Soil Physical Conditions and Plant Roots. CRC Press, Inc., Boca Raton, Florida, 1990.
4. **Gliński J., Stępniewski W.:** Soil Aeration and Its Role for Plants. CRC Press, Inc., Boca Raton, Florida, 1985.
5. **Hanks R.J., Askroft G.L.:** Applied Soil Physics. Springer-Verlag, Berlin, 1980.
6. **Hillel D.:** Introduction of soil physics. Acad. Press. Inc., 1982.
7. **Huszár I.:** Agromechanics. Int. Agrophysics, 1(1), 23-39, 1985.
8. Int. Agrophysics, 10(3), 1996.
9. Int. Agrophysics, 7(2-3), 1993.
10. Int. Agrophysics, 11(1-2),1997.
11. **Letey J.:** Relationship between soil physical properties and crop production. Adv. Soil Sci., I, 277, 1985.
12. **Malicki M.A.:** A reflectometric (TDR) meter of moisture content in soils and other capillary-porous materials. Zesz. Probl. Post. Nauk Roln., 388, 107, 1990.
13. **Malicki M.A., Plagge R., Renger M., Walczak R.T.:** Application of time-domain reflectometry (TDR) soil moisture miniprobe for the determination of unsaturated soil water characteristics from undisturbed soil cores. Irrig. Sci., 13, 65-72, 1992.
14. **Malicki M.A., Skierucha W.:** A manually controlled TDR soil moisture meter operating with 300ps rise-time needle pulse. Irrig. Sci., 10, 153, 1989.
15. **Malicki M., Walczak R.:** A gauge of the redox potential and the oxygen diffusion rate in the soil with an automatic regulation of cathode potential. Zesz. Probl. Post. Nauk Roln., 220, II, 447-451, 1983.
16. **Mazurek W., Walczak R.T., Sobczuk H.A., Baranowski P.:** The model investigation of soil water content and soil water potential impact on radiation temperature of meadow plant cover. Zesz. Pr~~ Post. Nauk Roln., 436, 93-100, 1996.
17. **Mohsenin N.N.:** Physical Properties of Plant and Animal Materials. Gordon and Breach Science Publ., New York, 1978.
18. **Mualem Y.:** A new model for predicting the hydraulic conductivity of unsaturated porous media. Water Resour. Res., 12, 513-522, 1976.
19. **Pellizzi G.:** Trends in agricultural engineering. Zĕmĕdelska Technika, 38, 55-270, 1992.
20. **Sitkey G.:** Mechanics of Agricultural Materials. Académiai Kiadó, 1986.
21. **Sławiński C., Sobczuk H., Walczak R.T.:** Submodel of bypass flow in cracking soils. Part 1 - Theory. Int. Agrophysics, 10, 189-195, 1996.
22. **Sławiński C., Sobczuk H., Walczak R.T.:** Submodel of bypass flow in cracking soils. Part 2 - Experimental validation. Int. Agrophysics, 10, 197-207, 1996.
23. **Sobczuk H.A., Plagge R., Walczak R.T., Roth Ch.H.:** Laboratory equipment and calculation procedure to rapidly determine hysteresis of some soil hydrophysical properties under non steady flow conditions. Z. Pflanz. Bodenk., 155, 157-163, 1992.
24. Sustainable Agriculture Systems. Lewis Publ. (Eds: J.L. Hatfield, D.L. Karlen). Boca Raton, 1994.
25. **Usowicz B.:** Statistical - physical model of thermal conductivity in soil. Polish J. Soil Sci., 25(1), 25-34, 1992.
26. **Usowicz B.:** A method for the estimation of thermal properties of soil. Int. Agrophysics, 7(1), 27-34, 1993.
27. **Usowicz B., Walczak R.:** Investigations and analyses of spatial variability of soil temperature. Int. Agrophysics, 6(1-2), 43-53, 1992.
28. **Van Genuchten M.Th., Nielsen D.R.:** On describing and predicting the hydraulic properties of unsaturated soils. Ann. Geopysicae, 3, 5, 615-628, 1985.
29. **Walczak R.T.:** New aspects of agrophysical metrology (in Polish). Nauka Polska, 4, 1993.
30. **Walczak R.T.:** Basic problems of mass and energy transfer in the soil-plant-atmosphere system. Zesz. Probl. Post. Nauk Roln., 346, 11-22, 1987.
31. **Walczak R.T.:** Selection and utilisation of modern devices in field experiments. Part II. Monitoring of soil physical parameters (in Polish). Zesz. Probl. Post. Nauk Roln., 447, 91-100, 1996.
32. **Walczak R.T.:** Utilisation of model investigations and

agrophysical metrology in horticulture (in Polish). Zesz. Probl. Post. Nauk Roln., 429, 25-32, 1996.
33. **Walczak R.T.**: Model investigations of retention curve dependency on soil solid phase parameters. Habilitation thesis. Problemy Agrofizyki, 41, 1984.
34. **Walczak R., Reszetin O., Czachor H.:** Transport water and heat in soil. Polish J. Soil Sci., 7(1), 19-25, 1974.
35. **Walczak R.T., Sławiński C., Malicki M., Sobczuk H.:** Measurement of water characteristics in soils using TDR technique: water characteristics of loess soil under different treatment. Int. Agrophysics, 7, 175-182, 1993.
36. **Walczak R., Usowicz B.:** Variability of moisture, temperature and thermal properties in bare soil and in crop field. Int. Agrophysics, 8(1), 161-168, 1994.
37. **Wild A.:** Russell's Soil Conditions and Plant Growth. 11th ed., Longman, London, 1988.