A

ABSORPTION

The process by which one substance, such as solid or liquid, takes up another substance, such as liquid or gas, through minute pores or spaces between its molecules. Clay minerals can take water and ions by absorption.

ABSORPTIVITY

Absorbed part of incoming radiation/total incoming radiation.

ACOUSTIC EMISSION

The phenomenon of transient elastic-wave generation due to a rapid release of strain energy caused by a structural alteration in a solid material. Also known as stress-wave emission.

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McGraw-Hill Dictionary of Scientific & Technical Terms, 6E, Copyright © 2003 by The McGraw-Hill Companies, Inc.

ACOUSTIC TOMOGRAPHY

A form of tomography in which information is collected from beams of acoustic radiation that have passed through an object (e.g., soil). One can speak of thermo-acoustic tomography when the heating is realized by means of microwaves, and of photo-acoustic tomography when optical heating is used.

Cross-references

Agrophysics: Physics Applied to Agriculture

ADAPTABLE TILLAGE

See *Tillage, Impacts on Soil and Environment*

ADHESION

The attraction between different substances, acting at surfaces of contact between the substances e.g., water and solid, water films and organo-mineral surfaces, soil and the metal cutting surface.

ADSORPTION

A phenomenon occurring at the boundary between phases, where cohesive and adhesive forces cause the concentration or density of a substance to be greater or smaller than in the interior of the separate phases.

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Cross-references

Adsorption Energy and Surface Heterogeneity in Soils
Adsorption Energy of Water on Biological Materials
Solute Transport in Soils
Surface Properties and Related Phenomena in Soils and Plants

Jan Gliński, Józef Horabik & Jerzy Lipiec (eds.), *Encyclopedia of Agrophysics*, DOI 10.1007/978-90-481-3585-1,

ADSORPTION COMPLEX

Collection of organic and inorganic substances in soil that are capable of adsorbing (absorbing) ions or molecules.

Cross-references

Adsorption Energy and Surface Heterogeneity in Soils
Surface Properties and Related Phenomena in Soils and Plants

ADSORPTION ENERGY AND SURFACE HETEROGENEITY IN SOILS

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Generalities

The potential energy of interaction of a single adsorbate molecule with a solid adsorbent can be described by the function $U(R)$, where $\{R\}$ is a set of coordinates necessary to define the position of the adsorbate molecule. Assuming that the adsorbate molecule is a sphere of diameter σ, its position is given by the Cartesian coordinates of its center, $R = r = (x, y, z)$. For molecules composed of several atoms, one needs to specify a multidimensional vector $\{R\}$ that determines the coordinates of all the atoms (or groups of atoms) building a given molecule. Formally, according to the classical statistical thermodynamics $U(R)$ is the sum of the interactions of N_a interaction centers located within a given adsorbate molecule, with N_s interaction centers located within a solid,

$$U(R) = \sum_{i \in N_s} \sum_{j \in N_a} u(r_{ij}), \tag{1}$$

where r_{ij} is the distance between the interacting centers. Of course, when quantum-mechanical treatment is employed, $U(R)$ is the difference of ground state energies between the molecule at the position $\{R\}$ and the ground state of a separated molecule.

For a selected adsorbate molecule, say a spherical molecule, the potential $U(r)$ can be used to characterize the surface. For a given set of coordinates x, y in the plane parallel (or tangential) to the solid the minimum of the function $U(r)$ with respect to the third coordinate, z, is often called "the adsorption energy," ε_{ad}. If ε_{ad} is independent of x, y, the corresponding surface is energetically uniform (or homogeneous). For crystalline surfaces ε_{ad} (and, of course, $U(r)$) is a periodic function of x, y. However, there exists a variety of surfaces that are neither uniform nor crystalline. In those cases, $\varepsilon_{ad}(x, y)$ may vary in a quite complicated manner with x, y and we call such surfaces energetically heterogeneous.

Energetically heterogeneous surfaces can be next classified into several groups, among which we can distinguish patchwise and random surfaces. In the case of random surfaces $\varepsilon_{ad}(x, y)$ varies quite randomly with x, y; for patchwise surfaces $\varepsilon_{ad}(x, y) =$ constant for x, y within consecutive regions Δ_i. Both random and patchwise surfaces are two limiting cases of surface topography that is defined by spatial correlations between the points x_i, y_i with given values of the energy $\varepsilon_{ad,i}$. We can distinguish correlations between pairs of sites, triples of sites, and so on (Bulnes et al., 2001).

The variation of the energy of adsorption results from several factors: the presence of different atoms or groups of atoms on the surface; geometrical irregularities including the presence of pores of different shape and dimensions, and so on. Of course, geometrical and energetic nonuniformities are correlated and the former is one of principal sources of energetic heterogeneity. Moreover, a given adsorbent may be a quite complex mixture of several interacting chemical species. Both energetic and geometric heterogeneities have a great impact on the adsorption process.

Description of adsorption on energetically heterogeneous surfaces

Accurate modeling adsorption on geometrically nonuniform surfaces is difficult and only in some cases it is possible to construct an adequate model for a solid. When it is possible, then computer simulations can be employed. However, the structure of great majority of environmental adsorbents, and soils in particular (see *Clay Minerals and Organo-Mineral Associates*; *Organic Matter, Effects on Soil Physical Properties and Processes; Parent Material and Soil Physical Properties; Soil Phases*) is extremely complex due to diversified mineral, organic, and ionic composition. Therefore, the application of approximate approaches is necessary. The most widely used methods are based on the so-called integral adsorption isotherm equation.

Suppose we know the function $\theta_l(p, \varepsilon)$ that describes the isotherm (surface coverage) on a uniform surface with the adsorption energy ε. Then, the isotherm on a heterogeneous surface can be approximated as

$$\theta(p) = N_m \int_{\varepsilon_{min}}^{\varepsilon_{max}} \theta_l(p, \varepsilon)\chi(\varepsilon)\mathrm{d}\varepsilon, \tag{2}$$

where p is the pressure, $\theta(p, \varepsilon)$ is the global (measured) adsorption isotherm, N_m is the monolayer capacity, and $\chi(\varepsilon)$ is the energy distribution function that yields a fraction of the surface characterized by the adsorption energy ε. The latter function satisfies the normalization condition

$$\int_{\varepsilon_{min}}^{\varepsilon_{max}} \mathrm{d}\varepsilon = 1, \tag{3}$$

where $[\varepsilon_{min}, \varepsilon_{max}]$ are the lower and upper integration limits. In many cases, these limits are assumed to be $[\varepsilon_0, \infty)$, where ε_0 is the liquefaction energy of the adsorbate. Equation 2 states that the total adsorption is just a weighted average of the isotherms on model, homogeneous surfaces, characterized by different values of ε. However, it means that the adsorption on each homogeneous surface occurs independently of the adsorption on other surfaces. The last assumption is satisfied only for a patchwise topography, or when the interactions between adsorbed particles are negligibly small. Despite of the above quoted limitations, Equation 2 has been widely used to describe adsorption on heterogeneous surfaces. Note that a quite similar approach is usually used to describe adsorption by porous solids. In the latter case, the weight function is just the pore size distribution function.

If the local adsorption isotherm and the energy distribution function are given by analytical expressions, Equation 2 can be integrated to yield an equation for the total adsorption isotherm. For example, if the local isotherm is just given by the Langmuir equation, $\theta_l(p,\varepsilon) = pK(\varepsilon)/[1 + pK(\varepsilon)]$, where $K(\varepsilon) = K_0 \exp[-\varepsilon/kT]$, k is the Boltzmann constant, T is the temperature, and K_0 is a constant, then one can show that the Temkin isotherm, $\theta(p) = \ln(1 + \mathrm{Kp})^{\gamma}$, corresponds to a constant energy distribution function; the Freundlich isotherm is associated with an exponential distribution and the Langmuir–Freundlich isotherm, $\theta(p) = Cp^{\gamma}/[1 + Cp^{\gamma}]$ – with a quasi-Gaussian distribution (Xia et al., 2006). In the above C, K and γ are constants. Numerous analytical expressions for the total adsorption isotherms obtained from Equation 2 can be found in the monographs of Rudziński and Everett (1992) and Jaroniec and Madey (1988).

The above method of derivation of isotherm equations can be also extended to the case of a multilayer adsorption. The multilayer local adsorption isotherm on a homogeneous surface can be described by the Brunauer, Emmet and Teller (BET) equation (Brunauer et al., 1938)

$$\theta_l(p,\varepsilon) = \frac{1}{1-x}\frac{c(\varepsilon)x}{1 + [c(\varepsilon) - 1]x}, \tag{4}$$

where $x = p/p_s$ is the relative vapor pressure, p_s is the saturated vapor pressure, and $c(\varepsilon) = \exp[-(\varepsilon - \varepsilon_0)/kT]$. For a quasi-Gaussian energy distribution, we obtain then the multilayer Langmuir–Freundlich isotherm of the form $\theta(x) = [1/(1-x)\{\tilde{c}x^{\gamma}/[1 + \tilde{c}x^{\gamma}]\}$ with $\tilde{c} = \exp\,[-(\varepsilon_{min} - \varepsilon_0)/kT]$ (Rudziński and Everett, 1992).

Evaluation of the energy distribution functions from the experimental adsorption isotherms

When the total adsorption $\theta(x)$ is measured experimentally and the local adsorption model is assumed, Equation 2 can be solved (analytically or numerically) with respect to the distribution function $\chi(\varepsilon)$. The main difficulty in evaluating $\chi(\varepsilon)$ is the ill-posed nature of Equation 2 for some of its kernels $\theta_l(p,\varepsilon)$. Therefore, if meaningful results are to be obtained, special care and the quality of experimental data are required (Jaroniec and Bräuer, 1986) The easiest way to obtain an approximate solution of Equation 2 goes through the so-called condensation approximation, according to which (Rudziński and Everett, 1992)

$$\chi(\varepsilon) = -\partial\theta[p(\varepsilon)]/\partial\varepsilon. \tag{5}$$

The condensation approximation replaces the local adsorption isotherm by a step function, i.e., every pressure is associated with the value of the adsorption energy, $p/p_0 = \exp(\varepsilon/kT)$, that corresponds to one half of the coverage of a given homotattic patch. The basic difficulty in this method is associated with an appropriate numerical differentiation of the total adsorption isotherm, $\theta[p(\varepsilon)]$. One of the methods that has been widely used for that purpose relies on the approximation of the experimental data by the so-called exponential adsorption isotherm (Jaroniec and Bräuer, 1986)

$$\theta(p) = \exp\left[\sum_{n=1}^{N} B_n\,(kT\ln(p/p_m))^n\right], \tag{6}$$

where $\{B_n\}$ are the coefficients and the pressure p_m is associated with the minimum adsorption energy via $\varepsilon_{min} = kT\ln(p_m)$. The distribution function resulting from Equations 5 and 6 is

$$\chi(\varepsilon) = \left[\sum_{n=1}^{N} nB_n(\varepsilon - \varepsilon_m)^{n-1}\right]\exp\left[\sum_{n=1}^{N} B_n(\varepsilon - \varepsilon_m)^n\right]. \tag{7}$$

Approximation of the experimental data using Equation 6 must be carried out under constraint that the function $\chi(\varepsilon)$ is nonnegative for the energies corresponding to the interval of pressures at which the isotherm was measured. Note that the above described method has been next extended to the case of adsorption on fractal surfaces (Sokołowska and Sokołowski, 2008).

The steps that lead to an appropriate solution of Equation 2 must involve a correct choice of the local adsorption isotherm and initial analysis of experimental data with respect to elimination of systematic and random experimental errors. Several numerical procedures for the evaluation of $\chi(\varepsilon)$ from experimental adsorption data have been proposed; numerous of them have been outlined by Jaroniec and Bräuer (1986) and Jaroniec and Madey (1988). One of the most accurate methods is the so-called regularization method (von Szombathely et al., 1992). Note that a quite analogous method was also employed to calculate the pore size distribution from experimental adsorption isotherms (Kowalczyk et al., 2003). Another quite accurate and numerically simple method was developed by Stanley and Guiochon (1993), who employed an expectation–maximization method of parameter estimation to calculate adsorption energy distributions from experimental adsorption isotherms. The method does not require any prior knowledge of the distribution function, or the analytical expression for the experimental isotherm, requires no smoothing of the isotherm data, and converges with high stability toward the maximum-likelihood estimate. The method is therefore robust and accurate at high iteration numbers. The test calculations carried out by Stanley and Guiochon proved that their method is more accurate than several previous approaches (Jaroniec and Madey, 1988).

One should also mention about an alternative theoretical approach to model adsorption by heterogeneous adsorbents that is based on the concept of quenched–annealed mixtures (Pizio, 2000). In the case of one-component adsorbate, the adsorption system is considered as a two-component mixture, in which one component (adsorbent) is frozen. The application of the so-called replica methodology (Pizio, 2000) allows them to calculate adsorption isotherms. Similarly, a planar heterogeneous surface can be modeled by "quenching" an imaginary "fluid of adsorbing centers" (Rżysko et al., 1999). This approach, although theoretically promising, has been not employed to model experimental data adsorption on environmental materials so far.

Energetic heterogeneity of soils

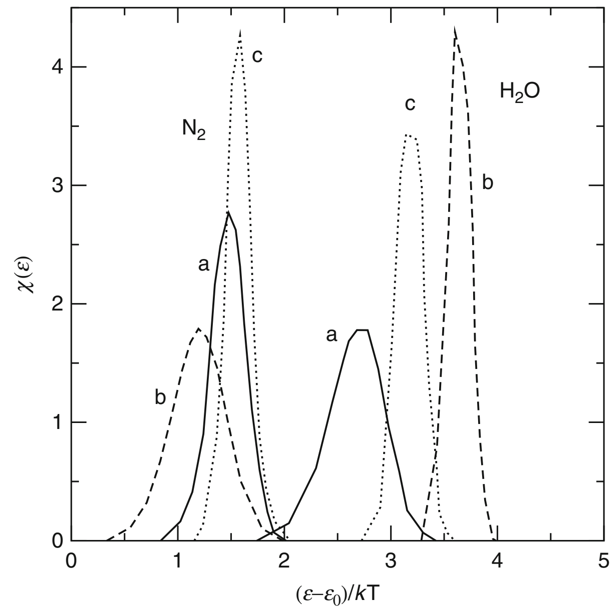
The concepts of adsorbent heterogeneity and the integral adsorption equation in particular have been widely used to study adsorption of vapors by soils (Bottero et al., 1993; Pachepsky et al., 1995; Józefaciuk and Bowanko, 2002; Sokołowska et al., 1999; 2002; Villiéras et al., 2002). The energy distribution functions and the average values of the energy of adsorption, $<\varepsilon>$,

$$<\varepsilon> = \int d\varepsilon \varepsilon \chi(\varepsilon) \quad (8)$$

obtained from experimental adsorption isotherms have been proved to be useful while discussing the mechanism of adsorption, the role played by selected constituents of soils and soil minerals in the adsorption process, to get insights into the changes in the soils caused by chemical and/or treatment, and so on.

Figure 1 shows exemplary energy distribution functions obtained from the numerical solution of Equation 2 applied experimental data of nitrogen and water vapor adsorption on alluvial soils (for details see Sokołowska et al., 2002). Of course, the energy of interaction of a single adsorbate particle with adsorbing surface depends on its chemical nature. Consequently, the results for both adsorbates are different. However, the energy distribution functions for nitrogen, as well as for water are described by narrow, Gaussian-like peaks. Such peaks indicate the existence of one major kind of adsorbing centers.

The energy distribution functions and their changes due to the changes or modifications of soils depend on the individual soil properties, but one should remember that function $\chi(\varepsilon)$ provides only a global energetic characteristic of a given surface. In order to associate its particular peaks to really existing adsorption centers, additional studies, e.g., spectroscopic measurements of adsorbed molecules, are necessary.



Adsorption Energy and Surface Heterogeneity in Soils, Figure 1 Examples of the energy distribution functions vs. dimensionless energy obtained from adsorption isotherms of nitrogen and water vapor on a sample of alluvial soil by Sokołowska et al. (2002). Labels (**a**), (**b**), and (**c**) denote horizons. (Reprinted from Sokołowska et al. (2002). Copyright (2002), with permission from Elsevier).

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Adsorption Energy of Water on Biological Materials
Clay Minerals and Organo-Mineral Associates
Estimation of Quartz Content in Mineral Soils
Organic Matter, Effects on Soil Physical Properties and Processes
Parent Material and Soil Physical Properties
Soil Phases
Specific Surface Area of Soils and Plants

ADSORPTION ENERGY OF WATER ON BIOLOGICAL MATERIALS

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Synonyms

Adsorption enthalpy; Adsorption heat; Isosteric heat of sorption

Definition

Adsorption energy (heat) represents the difference between the heat of evaporation the unit quantity of a substance from the product and the heat of evaporation the unit quantity substance from the pure liquid state in the same conditions (temperature, external pressure, product composition, etc.). The SI unit of adsorption energy is $J.mol^{-1}$.

The adsorption energy (heat) of water is usually calculated at constant moisture content (isosteric heat of adsorption).

Introduction

The biological materials are not simple substances and/or simple mixtures. Substances in biological materials form aggregates in which they bond one to the other (Physical Properties of Raw Materials and Agricultural Products). The consequence is that molecules of the individual substances have lower energy in the aggregates than in pure substance. These interactions of the individual substances in the aggregate are described by the chemical potentials (Daniels and Alberty, 1961).

For biological materials, the most important component is water (See also *Water Effects on Physical Properties of Raw Materials and Foods; Water in Forming Agricultural Products; Drying of Agricultural Products*) and that is why we deal here only with the adsorption of water. Water vapor in the surrounding air depends on the state of water inside the material. Water from the material can evaporate into the surrounding air or water can condense on the surface of the material. Both processes, evaporation and condensation, lead to equilibrium after some time. In this state, the properties of water inside a material can be described by the properties of water vapor. This equilibrium is related only to the "surface," most available water being in contact with water vapor; the product usually contains more water that is not in contact with the vapor. This water is usually more bond than the above mentioned more available "surface" water. Different mechanisms of water bonding in biological materials were observed. The most important are participation in solution, adsorption on surfaces (internal and external), adsorption in biological cells, and pore adsorption. Adsorption is not usually very strong when chemical adsorption is excluded.

The state of internal water can be expressed by the relative chemical potential that is termed water potential (Oertli, 1976; Moore, 1972). This term is in direct relation to the adsorption enthalpy. The state of water vapor in the surrounding air is well described by the relative pressure that is termed water activity (Daniels and Alberty, 1961).

Water potential: adsorption enthalpy

Water potential (Ψ) is directly given by the difference between the chemical potential of water in the material (μ_m) and the chemical potential of pure water (μ_0) in the same conditions:

$$\Psi = \mu_m - \mu_0 \quad (1)$$

The water potential can be expressed either in the usual SI units ($J.mol^{-1}$) or it could be recalculated into another SI expression, frequently into pressure (in Pa). The chemical potential is the relative Gibbs potential so that its value represents also the adsorption enthalpy in conditions that the difference between entropy of water in the material and entropy of water in the pure state can be omitted (Daniels and Alberty, 1961). Water potential is frequently used to describe the status of water in living organisms (See *Water Effects on Physical Properties of Raw Materials and Foods*) (Oertli, 1976) and in soil (Blahovec, 2008). Binding of water in the product is expressed by the negative value of water potential.

Water activity

Dimensionless term, water activity (a_w) of water solutions can be simply estimated by the formula (Daniels and Alberty, 1961)

$$a_w = e^{\frac{\Psi}{RT}} \quad (2)$$

where R is the universal gas constant (8.3145 $J.K^{-1}.mol^{-1}$) and T absolute temperature. Water activity then changes from 0 to 1 for water potentials from $-\infty$ to 0. In more complicated materials, water activity can be simply expressed as the ratio of fugacities of the material water (f_m) and pure water (f_0):

$$a_w = \frac{f_m}{f_0} \approx \frac{p_m}{p_0} \quad (3)$$

that could be approximated by the ratio of the partial water vapor pressures (p_m and p_0) above the corresponding water states (Daniels and Alberty, 1961). The definition of water activity by the pressure ratio is fully correct for water vapor described as an ideal gas; the water activity of the material is then given directly by the air humidity being in equilibrium with the material. The difference between water activity based on the fugacity and on the pressure increases with deviations of the water vapor properties from properties of the ideal gas, for example, with increasing moisture content of the material.

Water activity is a crucial parameter for the living activity of agroproducts and the activity of their components (enzymes, microorganisms, etc. – see Karel, 1975b, Fennema, 1976). This is very important for storage of agricultural products (See also *Physical Phenomena and Properties Important for Storage of Agricultural Products; Physical Properties as Indicators of Food Quality*).

Sorption isotherm

The vapor pressure of the solvent in a solution can be expressed by Raoult's Law (Daniels and Alberty, 1961; Karel, 1975a, Moore, 1972) and the relation between moisture content and water activity can be estimated on this base. In real water solutions and/or more complex materials, this relation is more complicated. It can be obtained experimentally at constant temperature in the form of a sorption isotherm that is the plot of moisture content (usually on dry basis) versus water activity at equilibrium and constant temperature. In most cases, the material is in solid and/or semisolid state (Rheology in Agricultural Products and Foods); in this case, the adsorption of water is understood and theoretically analyzed as a surface controlled process, that is, process based on water deposition on the (internal surface) of the material. Van den Berg and Bruin (1981) gave 77 types of different equations that can be used to describe water sorption isotherms in foodstuffs; more than 22 of them are theoretically based on water surface sorption. The most frequent are the Langmuir's isotherm, BET isotherm, and GAB isotherm.

The most frequent way to obtain the sorption isotherm at a sample consists in finding individual points of the sorption isotherm. Each point is obtained by determining the moisture content of a sample (by a gravimetric method) that was kept for long time, up to equilibrium, at constant temperature close to an oversaturated water solution of known water activity (Karel, 1975b).

Isosteric heat of sorption

A set of sorption isotherms obtained at different temperatures is the usual basis for determining the isosteric heat of sorption ΔH, that is, the difference between the heat of evaporation unit quantity of water from the product and the heat of evaporation of a unit quantity of water from the pure water in the same conditions. Isosteric heat of sorption of water is given by formula (Daniels and Alberty, 1961, Blahovec, 2008)

$$\Delta H = \left(R \frac{d(\ln a_w)}{d\left(\frac{1}{T}\right)} \right)_{MC} \quad (4)$$

where MC denotes that the derivative is calculated at constant moisture content. The experimental values of water activity are usually well given by an exponential function of reciprocal absolute temperature (see Equation 2) so that the isosteric heat of sorption is nearly independent of temperature.

The isosteric heat of sorption in real biological materials increases with decreasing water activity (decreasing moisture content) similarly as the absolute value of the water potential in Equation 2 at least at moisture contents higher than approximately 10% w. b. At lower moisture contents, Equation 2 loses its validity for real biological materials:

$$\Delta H_R \approx -\Psi_R \prec \Delta H_T \approx -\Psi_T \quad (5)$$

where index R denotes water in real biological materials and index T denotes data based on water vapor as an ideal gas.

Direct and indirect methods for determination of the heat of adsorption

Direct methods for the determination of the heat of adsorption meet experimental difficulties when they are applied to biological experimental materials (Heiss, 1968). The biological materials are sensitive to changes of external parameters (temperature, pressure, see also *Stomatal Conductance, Photosynthesis, and Transpiration, Modeling*) that usually lead to changes of the physical state of the biological material. Hence, the direct experimental methods have only limited application in the determination of the heat of adsorption of biological materials.

Among indirect methods, the most frequent is the above mentioned method based on the sorption isotherms. From the others, the methods based on the determination of the points of melting and evaporation can be also applied (Daniels and Alberty, 1961; Heiss, 1968). New ways for studying water sorption in biological materials have been developed (e.g., Nelson and Trabelsi, 2005).

The highest values of the isosteric heat of adsorption (20–30 $kJ.mol^{-1}$) are observed in biological materials at low moisture contents (lower than about 5% w.b.). These values are about one half of the heat of vaporization of water (Water in Forming Agricultural Products; Blahovec, 2007; 2008).

Conclusion

The adsorption energy of water (AEW) on biological materials depends on the material moisture content. At higher moisture contents, AEW increases with decreasing moisture content in a similar manner as the absolute value of water potential increases with decreasing water activity. At the lowest moisture contents (less than 5%), the AEW reaches in many cases nearly constant values 20–30 $kJ.mol^{-1}$ that represent about half of the heat of evaporation of water.

The AEW is well described by isosteric heat of sorption that could be easily obtained from sorption isotherms measured at different temperatures. Direct methods for measurement of AEW are difficult to apply to AEW of biological materials. Application of physical chemistry to the calculation of AEW usually fails either due to the limited applicability of ideal gas conception or complicated aggregate structure of biological materials.

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Rheology in Agricultural Products and Foods
Stomatal Conductance, Photosynthesis, and Transpiration, Modeling
Water Effects on Physical Properties of Raw Materials and Foods
Water in Forming Agricultural Products

ADVECTION

See *DNA in Soils: Mobility by Capillarity*

Cross-references

Soil–Plant–Atmosphere Continuum

AERATION OF AGRICULTURAL PRODUCTS

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Definition

Aeration, that is, forced ventilation of ambient or refrigerated air through stored products is necessary to maintain their quality. The main purpose of aeration is to minimize a risk of storage losses through equalizing temperatures in a bedding in order to minimize moisture movement, to cool product for pest control, and to stop product heating.

Background

Certain biological reactions generate heat and often it is necessary to remove it, that is, to cool the product. Heating and cooling (see *Heat Diffusion*) large amounts of biological material require energy and time so the knowledge about the process is necessary to optimize operations. Heating or cooling is not an uniform inside the volume of layer of material, rather heating or cooling front passes through the material. The velocity and thickness of the front are dependent on the air velocity (see *Air Flux (Resistance) in Plants and Agricultural Products*), the evaporation rate, the temperature difference, and the sizes of particles (see *Pore Size Distribution*). Usually, the air velocity is a crucial factor. In design of processes or equipment mathematical equations describing heating or cooling are used that are derived with necessary simplifying assumptions. Usually, the most important assumptions are as follows: the material is isotropic (see *Isotropy and Anisotropy in Agricultural Products and Foods*) in terms of thermal and mass diffusivity; the temperature, moisture content, and porosity of the layer are initially identical in the volume and porosity does not change during the process; the temperature of the moving air does not change observably, walls limiting the considered volume are isolated, and fluctuations of external temperature are negligible. Differential equations are formulated and solved numerically that allow to estimate movement of heat front.

Grain aeration

The process of aeration of grain will be described below as probably the most common at the farm. Grain is good insulator (see *Grain Physics*) and heat loss from it is relatively low as compared to other materials. Grain is usually placed in a storage silo in the fall and its portion near the center tends to remain near the temperature at which it came from the dryer or field. The grain near the silo wall tends to cool to near the average outside temperature. With a decrease in the ambient temperature, the difference between the temperature in the center and near the wall produces air currents inside the grain mass. The colder air near the wall is denser and tends to fall, while warmer air flows up through the center of grain mass. Warmer air contains more moisture and when it reaches top center of the silo fill it cools to a point at which it cannot hold all moisture it had absorbed. The excess moisture condenses at the top layer of grain and creates an environment enhancing mold and insect growth. The opposite situation occurs in warmer periods, the moisture condenses near the bottom center of grain mass.

The problem of air currents within the grain mass may be minimized by keeping the temperatures near the center close to the average temperature near the wall of the storage silo (Loewer et al., 1994). To accomplish this aeration fans may be used that pull air down through the grain until the temperature of grain mass is within 5°C of the average monthly temperature. Aeration air can move either up or down through the grain mass. Most fans have the ability to either push or pull, however, airflow volumes and power requirements will often change due to direction. It is not necessary to cool the grain mass below 5°C, because the activity of typical storage fungi is very low below this temperature. In spring, warming of grain is necessary if extended storage (post June) is required or if the temperature of grain is below 0°C. Typical aeration airflow rates range from 1 to 2 L of air per second per cubic meter of grain (1–2 L/(s m^3)). Higher rates should be used (2–6 L/(s m^3)) if grain is stored at higher moisture levels or if a large variance in incoming moisture levels exist. An aeration system cannot be considered a drying (see *Drying of Agricultural Products*) system since natural air drying rates are at least 10 times longer.

Conclusion

Aeration and controlled atmosphere storage are still under development to elaborate efficient methods for control of temperature and moisture of product, as well as for elaboration of optimum strategies specific for crop, storage structure, and climatic conditions. Currently, investigations are conducted on characterization of bedding anisotropy and including this into strategies of aeration control (Navarro and Noyes, 2001).

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Cross-references

Air Flux (Resistance) in Plants and Agricultural Products
Drying of Agricultural Products
Grain Physics
Heat Diffusion
Isotropy and Anisotropy in Agricultural Products and Foods
Pore Size Distribution
Water Effects on Physical Properties of Raw Materials and Foods

AERATION OF SOILS AND PLANTS

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Synonyms

Gas exchange in soils; Oxygenation of soils and plants; Oxygenology of soils and plants

Definition

Aeration of soils and plants is a term used in wide sense as a name of complex issues related to air transport and distribution in soil and its effect on processes occurring in soil and plants. Sometimes it is used in a narrow sense to denote gas exchange between soil and atmosphere, or only oxygen content in soil air or even as a name for a process of artificially forcing air into the soil (Gliński and Stępniewski, 1985).

Introduction

In soil medium intensive production, transformations, and consumption of a number of gases, which are transported to and from the atmosphere, take place. These processes are not only important for the production of plant biomass but also play an important environmental role.

The most important soil gasses are oxygen (indispensable for root respiration and important for microbial metabolism and for numerous biochemical and chemical processes) and carbon dioxide (product of oxic respiration of plant roots, microorganisms, and mezo- and macrofauna, as well as anoxic microbial respiration and fermentation). Nitrogen, important for its fixation by some microbes, draws less attention because it is considered as non-limiting due to its abundance.

Soil air contains, moreover, a number of gases occurring in trace amounts such as nitrous oxide (N_2O), nitrogen oxide (NO) and dioxide (NO_2), ethylene, ammonia (NH_3), and hydrogen sulfide (H_2S). An intermediate position occupies methane which under dryland conditions occurs in trace amounts but under wetland conditions and under landfill conditions can occupy a substantial fraction of the soil air. Dependently on the aeration status, the soil can be a source or a *sink of greenhouse gasses* such as CH_4 and N_2O.

Pathways of gas exchange

There are two essential pathways of the gas transport in the *soil–plant–atmosphere continuum* (see *Soil–Plant–Atmosphere Continuum*): the soil pathway and the internal pathway through the plant tissues (Figure 1). The first one prevails in soils cultivated under dryland conditions, while the plant pathway dominates in natural and constructed wetlands and paddy fields (e.g., Yan et al., 2000). If the soil is without plants, the downward transport of gases practically ceases while the gases generated in the soil such as CO_2 and CH_4 are released to the atmosphere by ebullition.

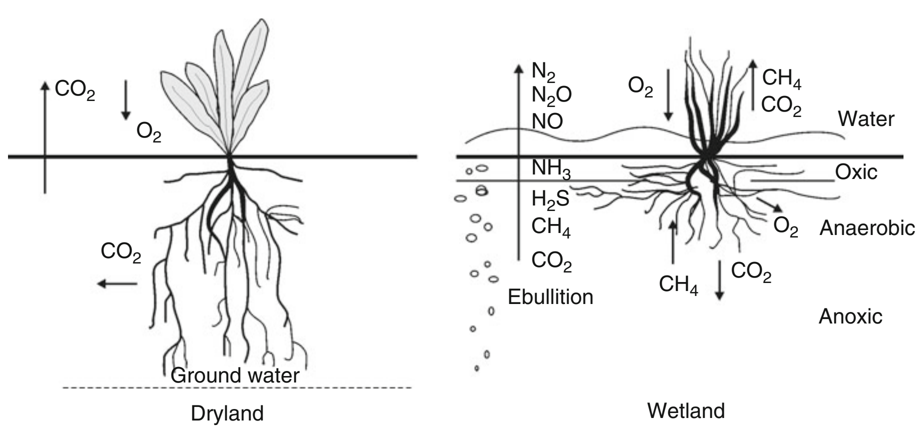
Between these two pathways, there are numerous intermediate situations with different contributions of soil- and plant-mediated transport of gases dependently on the land use and tillage influencing air-filled porosity, gas diffusion coefficient, and air permeability of soil (Stępniewski and Stępniewska, 2009). Agricultural land use is connected mainly with dryland conditions as wetland rice cultivation produces about 20% of food calories (IRRI, 2005). There are also examples of intermediate systems such as midseason drainage of paddy fields to prevent toxicity of sulfides (Kanno et al., 1997), combining cultivation of lowland rice with dry season crops (So and Ringrose-Voase, 2000) as well as so-called system of rice intensification characterized by change from permanent flooding to intermittent irrigation (Dobermann, 2004) to improve the oxygen supply to rice roots (Stoop et al., 2002).

Mechanism of gas exchange

There are two essential mechanisms of gas exchange in soil medium: mass flow or advection (convection) and molecular diffusion. Both these mechanisms can take place in soil pores as well as in plant tissues. The relative contribution of both mechanisms of gas exchange can vary within wide limits dependently on the conditions.

Mass flow

The driving force of mass flow is pressure gradients appearing within soil or plants due to fluctuations of atmospheric pressure, variability of temperature, changes of groundwater depth, infiltration of rainwater, as well as humidity-induced convection in leaves and Venturi convection caused by wind action (Armstrong et al., 1996). Of these drivers only fluctuations of atmospheric pressure may be of importance in the soils with very deep impervious layer.



Aeration of Soils and Plants, Figure 1 Model of the two pathways of gas exchange in the atmosphere–plant–soil continuum. Dryland conditions – oxygen is supplied to the plant roots via the soil. Wetland conditions – oxygen is transported through the tissues of the plant itself.

In case of *laminar flow* (see *Laminar Flow*) usually occurring in soil, when the Reynolds's number < 1 (Currie, 1970) the movement of gases is described by Darcy's equation:

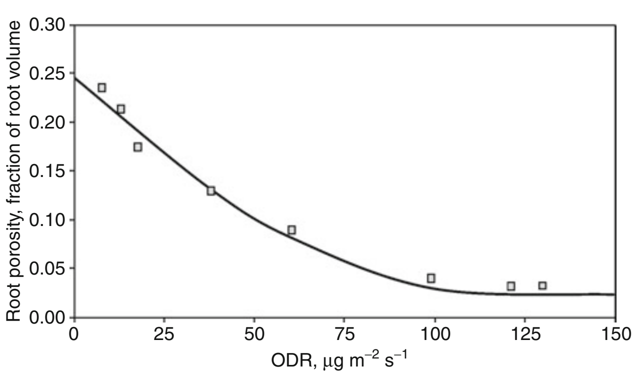
$$\frac{dV}{dt} = -A\,\frac{k}{\eta}\,\frac{dp}{dx} \qquad (1)$$

where dV/dt is the volumetric rate of gas flow, $m^3\,s^{-1}$, A is the cross-sectional area of the porous medium, m^2; η is the dynamic viscosity of the gas, $kg\ m^{-1}\ s^{-1}$; dp/dx is the pressure gradient, $Pa\ m^{-1} = kg\ m^{-2} s^{-2}$; and k is the air permeability, m^2.

According to Gliński and Stępniewski (1985), the values of air permeability in soil are within the range of $0.01–500 \times 10^{-12}\ m^2$. Air permeability depends in general terms on the quantity and quality of air-filled pores. The latter term relates to the pore size distribution, continuity, and tortuosity, which, in turn depend on the arrangement of soil particles, on soil bulk density, and water content. Advective gas flow depends on the fourth power of the pore size.

Morphological changes within plants are very important adaptation to flood conditions. They include development of a shallow root system, formation of adventitious roots of high porosity, formation of aerenchyma within roots (Gliński and Stępniewski, 1985), and development of aerial roots or pneumatophores (e.g., Purnobasuki and Suzuki, 2005).

The internal *air flux* ability of the plant tissues can be a permanent feature or it may become apparent or enhanced under oxygen deficiency conditions (Figure 2). Internal transport of oxygen via plant roots can cover not only oxygen demand of the plant roots, but also can protect the plants against Fe^{2+} and H_2S toxicity (Jayakumar et al., 2005). It should be emphasized that an increase of internal porosity of root tissues increases both air permeability as well as gas diffusion coefficient.



Aeration of Soils and Plants, Figure 2 The relationship between oxygen availability in soil medium as characterized by oxygen diffusion rate (ODR) and the internal porosity of rice roots. (Modified from Ghildyal [1982].)

Diffusion

The basic mechanism of gas exchange in the soil medium and within the plant tissues is the concentration diffusion induced by concentration gradients.

The diffusive flow f_x of a gas within a porous medium is described by the first Fick's law.

$$f_x = -D\,dC/dx \qquad (2)$$

The above equation says that the uniaxial diffusion flow (f_x) of an agent through a unit cross-section, in a unit of time, is proportional to the concentration gradient (dC/dx) and to the diffusion coefficient D characterizing the mobility of the agent in a given medium.

Coefficient of gas diffusion in soil depends on the kind of gas, its temperature, and pressure, and also on the amount of air-filled pores, their continuity, and shape which depend on the spatial arrangement of soil particles and on distribution of water. The diffusive properties of a soil medium are usually characterized by the relative diffusion coefficient D/D_o, being the ratio of gas diffusion coefficient in soil D, to that of the same gas in atmospheric air D_o, under the same pressure and temperature conditions. The D/D_o value does not depend on the temperature, pressure, or the kind of the diffusing gas.

The influence of *soil bulk density* and soil moisture tension on D/D_o is presented in Figure 3. The value of D/D_o in soil is usually below 0.2. It increases with soil moisture tension, and rapidly decreases with soil bulk density. It should be stressed out that gas diffusion coefficient in porous media does not depend on the size of the pores, as long as the pore diameters are greater than the mean free path of the molecules of the gas under consideration. (Gliński and Stępniewski, 1985). This limit is the pore diameter of 0.10 μm. In the case of soil, pores of that size are emptied of water at soil moisture tension levels over 3 MPa (pF > 4.5), i.e., at moisture contents lower than the permanent wilting point. Thus, gas diffusion within macropores (above 30 μm) as well in the mezopores (30–0.2 μm) containing usually plant available water does not depend on the pore size.

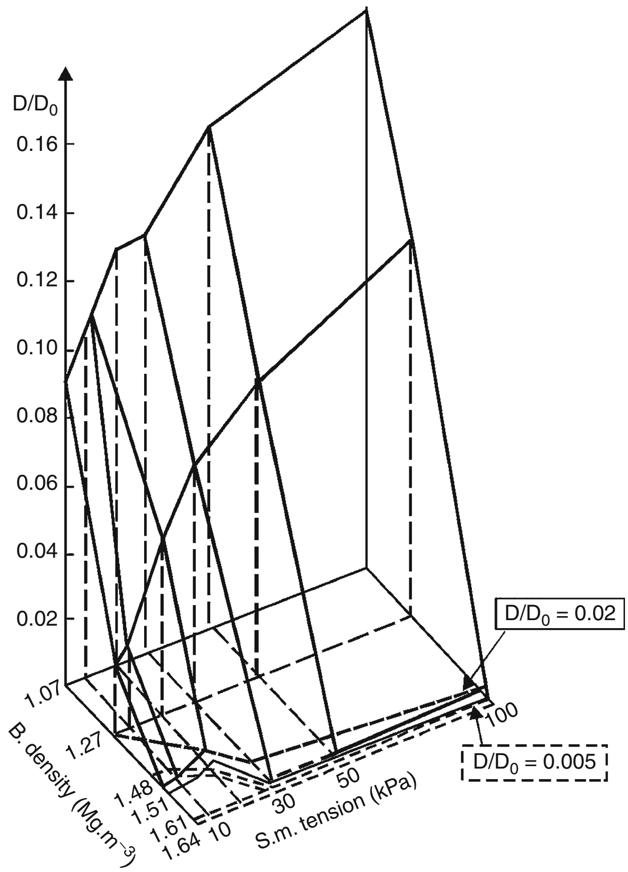
D/D_o usually shows a curvilinear relationship versus E_g, as shown in Figure 4. It can be described by an empirical power model in the following form:

$$\frac{D}{D_o} = \gamma E_g^{\mu} \qquad (3)$$

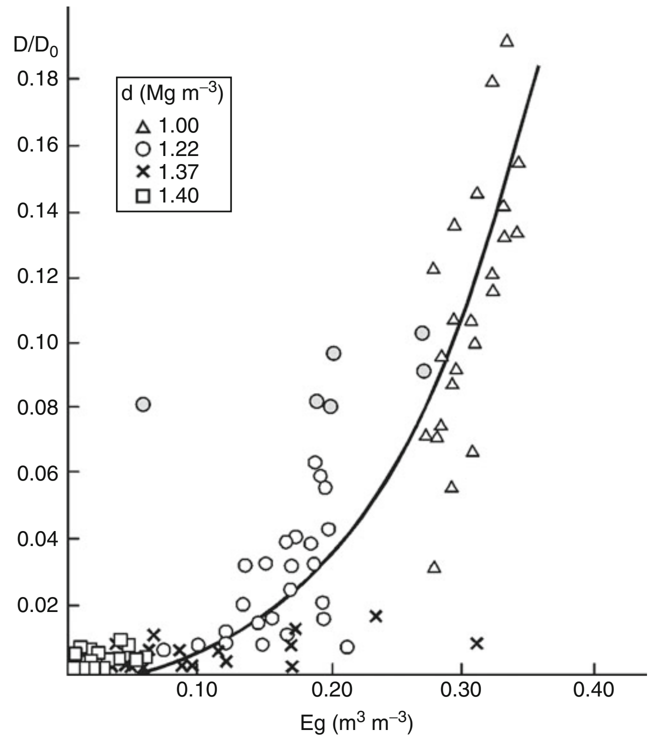
where γ and μ are empirical coefficients characterizing the porous material.

The author was unable to find literature data related to direct measurements of gas diffusion coefficients within living plant tissues.

It should be underlined that the composition of air within the intra-aggregate pores may differ from that in the inter-aggregate pores due to soil heterogeneity. The former pores contain less oxygen and more



Aeration of Soils and Plants, Figure 3 Dependence of relative gas diffusion coefficient in a loamy textured Phaeozem (Kock, Poland) on soil moisture tension and bulk density. (Modified from Stępniewski [1981].)



Aeration of Soils and Plants, Figure 4 Relationship of D/D_o to air-filled porosity E_g, of silt Fluvisol at different bulk densities d. (Modified from Stępniewski [1981].)

carbon dioxide compared to the inter-aggregate pores (e.g., Zausig et al., 1993; Højberg et al., 1994; Horn, 1994; Horn and Smucker, 2005).

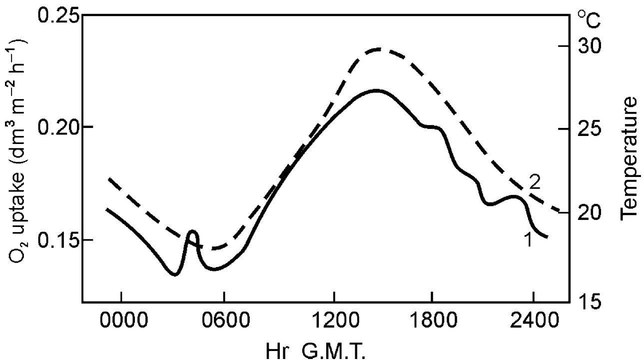
Oxygen

Oxygen is taken up by the soil due to respiration of microorganisms and plant roots. Respiration of soil microorganisms depends on the availability of oxygen, organic carbon, and nutrients as well on temperature and water content. The temperature interval for microbial growth ranges from −12°C to 110°C. Microorganisms with respect to their temperature requirements are divided into psychrophilic, mesophilic, and termophilic (Paul and Clark, 1998). A new term "hypertermophiles" denotes extreme thermopiles growing in the temperature range from 60°C to 110°C. Soil contains a mixture of different groups of microorganisms and its respiration rate increases two to three times with the increase of temperature by 10°C until the temperatures of break of metabolism (at about 60–70°C).

With respect to oxygen requirements, soil microbes are divided into obligate oxic, facultative anoxic, and obligate anoxic organisms (obligate anaerobes). A special group of microorganisms constitute microaerophiles characterized by oxygen optimum of order 2–10% by volume (Black, 1996). Oxic microorganisms utilize oxygen as a terminal electron acceptor from the cytochrome oxidase.

Soil microbial activity depends both on oxygen and carbon dioxide concentration, independently. Carbon dioxide is a carbon source for autotrophic microflora. Dommergues and Mangenot (1970) reported 2–14% CO_2 as the optimal range for the growth of these bacteria. For other microorganisms, carbon dioxide is an inhibitor of respiration and growth although some microorganisms display metabolic stimulation by low CO_2 concentration and inhibition above a certain CO_2 concentration (Dixon et al., 1998; Sierra and Renault, 1995).

The dependence of microbial respiration on water content shows a maximum corresponding to the range of optimal availability of oxygen and water. With respect to water requirements, the soil microorganisms are divided (Gliński and Stępniewski, 1985) into hydrophilic (disappearance of activity at pore water pressure > −7.1 MPa), mesophilic (disappearance of activity within the pore water pressure interval from −7.1 to −30 MPa), and xerophilic (disappearance of activity at pore water pressures < −30 MPa). Under field conditions, the rate of soil



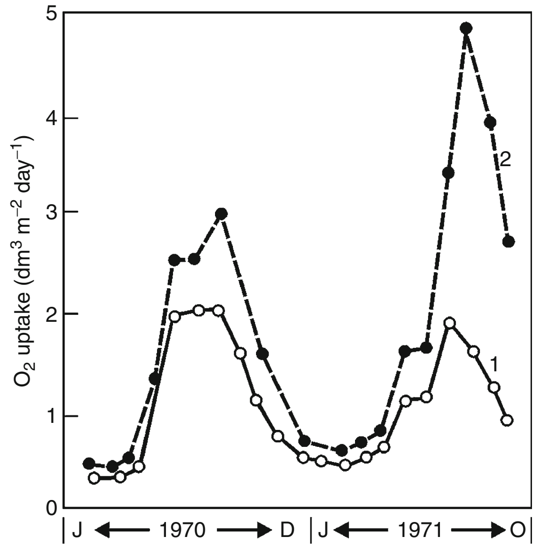
Aeration of Soils and Plants, Figure 5 Diurnal dynamics of soil respiration rate as measured by oxygen uptake and temperature. (Modified from Currie [1975].)

microbial respiration is usually within the range from 0.1 to 10 mg $m^{-3}s^{-1}$ (Gliński and Stępniewski, 1985).

The root respiration rate depends on plant internal factors such as plant type and development stage, root mass distribution, dimensions, and physiological age of the tissue, as well as on external factors such as temperature and the availability of water and nutrients. It should be emphasized that soil microbial activity increases in the presence of plant roots due to production of root exudates being a source of easily available carbon for microorganisms. Respiration rate of the root tissues is about two orders of magnitude of that of the soil itself and ranges from 10 to 50 mg $m^{-3}s^{-1}$ (Gliński and Stępniewski, 1985).

Oxygen uptake by a cropped field is a sum of microbial and root respiration and under field conditions is of order of several tons of oxygen per hectare and year (Gliński and Stępniewski, 1985). Soil respiration under field conditions (Figure 5) shows a maximum in the afternoon and minimum before sunrise. In the moderate climate zone, the annual dynamics of oxygen uptake under field conditions is characterized by a summer maximum (Figure 6). It should be emphasized that the presence of plants may elevate the oxygen uptake more than twice.

The oxygen deficiency in soil affects the plant performance directly by limitation of root respiration, of energy supply, and changing the metabolism in the root tissue itself, as well as indirectly by inducing chemical and biological changes in the surrounding soil (e.g., *oxidation–reduction reactions* (see *Oxidation–Reduction Reactions in the Environment*), accumulation of phytotoxic substances, changes of pH and ion exchange equilibria). Effects of deficient aeration can be manifested in plant roots in the form of ethanol and ethylene generation, reduced water permeability, growth inhibition, and necrosis. The shoot response comprises *stomatal* closure, chlorosis, epinasty, leaf senescence and abscission, partial or complete suppression of *photosynthesis* (see *Photosynthesis*), and growth leading to reduction of biomass and yield (Glinski and Stępniewski, 1985).



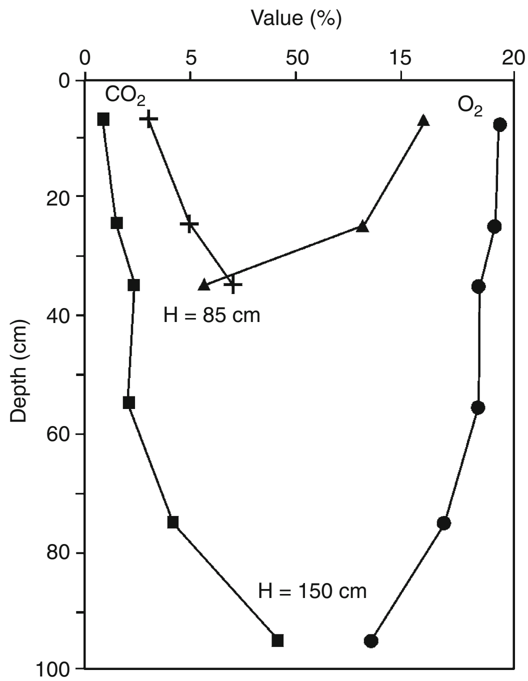
Aeration of Soils and Plants, Figure 6 Annual dynamics of soil respiration as measured by oxygen uptake rate in an uncropped (1) and cropped (2) soil under moderate climate conditions of England. (Modified from Currie [1975].)

Carbon dioxide and other gases

Production of carbon dioxide in soil under oxic conditions is directly related to oxygen uptake and all the factors influencing oxygen uptake affect also the emission of carbon dioxide.

Because of complementary character of oxygen uptake and carbon dioxide production their sum in soil air is usually about 20% by volume (cf. Figure 7). It means that also their fluxes between soil and the atmosphere are approximately equal. Concentration of oxygen in soil air decreases with depth and that of CO_2 increases. The composition of soil air is a decisive factor for microbial and plant metabolism, for many *oxidation–reduction reactions* and oxidation state of numerous soil nutrients, as well as for soil fertility and crop productivity. It should be kept in mind that under anoxia CO_2 can be produced without oxygen consumption (sum of O_2 and CO_2 >20%) and the emission of CO_2 from the soil exceeds the volume of oxygen taken up. However, long-term CO_2 emission under anoxia is reduced, what leads to carbon accumulation in soil.

Soil aeration state effects not only global turnover of oxygen and *fluxes of greenhouse gases* (see *Greenhouse Gas Fluxes: Effects of Physical Conditions*) such as carbon dioxide, methane, and nitrous oxide but also the emission of ammonia, NOx, and ethylene. Methane emission increases under anoxic conditions. Ethylene is generated within plants under moderate hypoxia. Nitrous oxide is formed and is stabile under moderate hypoxia and undergoes decomposition both under oxic conditions and under severe anoxia. Ammonia under oxic conditions undergoes oxidation to nitrates.



Aeration of Soils and Plants, Figure 7 Distribution of oxygen and carbon dioxide concentration in a gley meadow soil (Garbow, near Lublin, Poland) at two levels of ground water on 1971.06.19 (ground water level *H* = 85 cm) and the same point on 1971.09.04 (*H* = 150 cm). (From unpublished data of Stępniewski.)

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Cross-references

Air Flux (Resistance) in Plants and Agricultural Products
Bulk Density of Soils and Impact on Their Hydraulic Properties
Climate Change: Environmental Effects
Greenhouse Gas Fluxes: Effects of Physical Conditions
Greenhouse Gases Sink in Soils
Laminar and Turbulent Flow in Soils
Oxidation–Reduction Reactions in the Environment
Oxygenology
Soil–Plant–Atmosphere Continuum
Stomatal Conductance, Photosynthesis, and Transpiration, Modeling

AERODYNAMICS

See *Cultivation Under Screens, Aerodynamics of Boundary Layers*; *Grains, Aerodynamic and Geometric Features*

AFTER HARVEST TECHNOLOGY

See *Mechanical Impacts at Harvest and After Harvest Technologies*

AGGREGATE STABILITY

See *Cropping Systems, Effects on Soil Physical Properties*

Cross-references

Soil Aggregates, Structure, and Stability

AGGREGATION INDICES

Soil aggregation may be determined through the following indices: dispersion ratio, Wischmeier's erodibility index, clay dispersion index, clay flocculation index, geometric mean diameter and mean -weigh diameter.

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AGRICULTURAL PRODUCTS

See *Agrophysical Objects (Soils, Plants, Agricultural Products, and Foods)*; *Agrophysics: Physics Applied to Agriculture*

AGRICULTURAL RAW MATERIALS

See *Physical Properties of Raw Materials and Agricultural Products*

AGRICULTURE AND FOOD MACHINERY, APPLICATION OF PHYSICS FOR IMPROVING

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Definition

Physics is the science concerned with the study of matter and natural forces, such as light, heat, movement.

Design is an intellectual activity; it is the oldest mental process engaged in by man to solve complex problems, develop and improve technical systems, including farming and food processing machines. Design is a process of drawing logical conclusions from empirical observations. It enables man to create artificial objects that support his existence and to introduce technical systems into the natural environment.

A machine is a set of interconnected elements that perform a given set of operations, carry the load and the moment of force to perform useful work as an energetic effect, and transform any type of energy into mechanical energy or mechanical energy into a different type of energy. Motion is transferred by mechanisms.

Introduction

The primary goal of physics is to examine the material world and search for the truth and the fundamental properties of matter on the assumption that the laws of physics are consistent and universal. Physics studies natural objects with the application of universal methods, concepts, and laws. Physical sciences support the design of farming and food processing machines by solving complex problems relating to the physical properties of soil, organic materials, and food products with the use of methods that involve the determination of physical quantities and process descriptions, based on the principles of mechanics, thermodynamics, optics, electrodynamics, electronics, acoustics, and nuclear, molecular, and solid-state physics, as well as the principles of other modern fields of physics.

Rising competition in food production requires product quality growth and production costs reduction. Physical prosperities of raw materials make designing agricultural machinery and food processing machinery difficult. Precise knowledge of raw material prosperities is a condition to create appropriate food processing technologies and machinery. There are many problems to solve in machine designing, e.g., soil degradation, excessive chemicalization, food safety, etc. Sciences as agrophysics, agricultural engineering, food engineering, and other related sciences as mechanics, mechatronics, computer sciences, genetic engineering are used to help with gathering and receiving information for machine designing.

Changing rapidly global economy uses robots on a big scale in food production. Today human work in food production is replaced by machinery with complicated mechanisms, working units, sensors, and board computers. In current mechanical production dynamic development of mechanization, atomization and robotics takes place.

The importance of the physical properties of raw materials and food products in machines designing

Animate and inanimate matter differs as regards the values of state parameters such as temperature, pressure, radiation field intensity, and humidity. Live cells of animate matter used in the production of food have a highly complex microstructure, and its specific attributes, the observed chemical and biological processes reflect the universal laws of physics. The laws of physics attributed to complex systems imply various characteristic properties that have to be taken into account when designing food processing machines. Raw materials and food products have unique physical characteristics such as stretch, location, velocity, mass, momentum, temperature, color, and chemical and biological attributes. The raw materials used in the production of foodstuffs are examined with the use of physical methods to select the appropriate working parameters of the designed farming and food processing machines. The study of physical phenomena occurring in plant and animal material, i.e., anisotropic objects, in an unstable and an unpredictable environment poses a challenge for contemporary physics which, in addition to investigating the occurring processes, accumulating data and expanding our knowledge base, also aims to expand the intellectual capacity of technical sciences and offers solutions to specific problems. Scientific knowledge should have a practical dimension, and it should satisfy man's nutritional needs. Physical phenomena are described with the involvement of measurable properties, referred to as physical quantities. The process of examining the physical phenomena attributed to raw materials for the food industry can be divided into several stages. The first stage involves the selection of parameters that support the investigation of the studied object's suitability for processing and its description. The method of measuring the selected parameters is determined at the second stage. At the third stage, researchers develop the general concept and the structure of measuring equipment; they select the units of measurement and calibrate tools. At the following stage, measurements are performed at the required level of precision, the results are analyzed, and conclusions are formulated. At successive stages, the obtained results are applied to design and upgrade farming and food processing machines.

The relationship between motion and the force of raw material and food product molecules at the microstructure level is very important during the construction of farming and food processing machines. Motion is described with the use of parameters such as the components of a position vector that changes over time, which are attributed to the discrete morphological elements of a biological object. The measured quantities include distance, angle, and time. The correlation between the above quantities is investigated with the use of mathematical formulas. The human senses do not respond to many physical phenomena, including field and radiation. Such phenomena are often encountered in food processing technology. They are measured with the application of detectors that convert various pulses into observable signals. Detectors are clocks, weighing scales, thermoscopes, baroscopes, electroscopes, spectroscopes, microscopes, etc. A measuring device is closely interrelated with the physical quantity that is being measured at a given level of precision. Measurement precision determines the quality of physical observation. The results of measurements in a discrete system are expressed in the form of a finite set of numbers to which quantitative data are attributed. The studied processes involve recurring phenomena and phenomena that constitute the laws of physics. Those phenomena can be used to formulate theoretical structures and design many practical applications. The laws of physics are expressed in the form of mathematical relations between symbols representing different quantities. The discovery of new, validated laws of physics expressed by equations and inequations supports the examination of the resulting consequences. The application of physics theories in engineering and machine construction, including farming and food processing equipment, is important for the process of designing processing technologies. The physical properties of raw materials are transformed during processing into food products. The principal physical quantities describing a particle of the studied raw material or product are particle mass, vectors of position, and forces applied to those particles. If those quantities are known at a given time, then the velocity and acceleration of particle mass moved by that force is also known. Other quantities include momentum, angular momentum, and torque. Newton's laws of dynamics, described as a system of three quadratic differential equations for unknown time functions, support an infinite number of solutions. A fixed solution can be obtained only by determining the initial conditions.

In the process of building farming and food processing machines with the use of laws of physics that describe the general relationships associated with an infinite number of physically admissible solutions, a specific physical situation at a given point in time should be determined and implemented. Food engineering deals with various objects, including elementary particles, atoms, cells, tissues, ions, molecules, systems of microscopic and macroscopic particles as well as fields. One of the many goals of food engineering is the use of physics theories, namely the laws of physics written down in mathematical form, in a strictly defined environment. The above also applies to farming and food processing equipment, raw materials of plant and animal origin, and end products. For a physics theory to be useful in the process of solving technical problems, the number of predictions has to be consistent with experimental results. Established physics theories are not always fit for use in farming and food engineering. Despite their universal character, the applicability and precision of those theories may be limited in this particular context. If this is the case, a theory has to be adapted to a given situation to ensure a higher level of accuracy and consistency with the experiment. Experiments support the discovery of new physical phenomena and new attributes of technical and biological objects (Shao et al., 2009), and they are of paramount importance in the process of solving technical problems in agriculture, food engineering, and production. The measurements used to determine the physical quantities of the studied raw materials and food products contribute to the discovery of rules, correlations, structures, and dependencies. These experimental and intellectual methodological operations support the development of new concepts, conceptual structures and theories, the discovery of important phenomena for biological objects and dynamic causal relationships. The acquired knowledge on raw materials and food products, expressed in mathematical form, enables researchers to examine and determine the effect of changes in the physical qualities of the studied objects owing to different factors (conditions), to subject their findings to a critical evaluation and formulate logical conclusions. A physics theory that is free of logical and mathematical contradictions is a venture point for explaining causally connected facts, and it supports the prediction of new, unknown facts.

Many problems in agricultural and food engineering may be solved with the use of data in the existing knowledge database. Scientists developing new farming and food processing machines rely on information describing the physical properties of raw materials and food products as well as established scientific theories and laws of physics. Biological objects have a complex structure. The attributes of complex objects are determined by the laws and properties applicable to their components. Their geometric form follows from the surface structure of the morphological components of a biological object. Physics and its laws are closely related to natural sciences, which is why the laws of science have many applications in agricultural and food engineering, in particular in describing working processes and developing new technologies and machines. A sound theory of elementary particles should support the discovery of new phenomena and laws that may be applied in designing new technologies for processing a given type of raw materials into food products with the anticipated properties. As a rational science supporting the development of formal languages for the precise description of abstract concepts and relations, mathematics plays an important role in the physical description of the actual condition of farming and food processing machines. From among a variety of mathematical equations describing a given phenomenon, scientists have to choose the propositions, concepts, and statements that are fit for use in the process of building models of farming and food processing machines and modeling working processes in food production (Mieszkalski, 1996; Hardin and Searcy, 2009). Many biological objects with technical applications can be described with the use of geometric and mechanical models as discrete structures. A system of spatially distributed mass particles may serve as a model of raw materials and food products. The distance between mass particles is modified under the influence of the applied force. The physical quantities indicating displacement over time are described with the use of mechanics, thermodynamics, and other existing theories.

The design of new farming and food processing machines as well as food processing technologies relies heavily on mathematical modeling, which will develop as new advances are made in IT and computer systems. A preferred mathematical model for describing physical processes in farming and food engineering should have the widest possible range of applications, it should deliver a high degree of precision and, above all, it should support the prediction of experimentally validated events.

Many discoveries have been made as regards measuring devices for observing the structure of biological objects of plant and animal origin. Small objects in the structure of the studied raw materials are investigated with the use of microscopes. Vast advancements have been made in the field of microscopy, leading to the development of electron and confocal microscopes (Entwistle, 2000; Danilatos and Postle, 1982; Inoue, 1986). New solutions simplifying the observation of the spatial structures of those objects are likely to be introduced in the future. Empirical knowledge on the spatial distribution of particles with a complex shape will contribute to the development of more accurate particle models as well as theories that offer practical implications for farming and food engineering.

Testing raw materials and food products

There is a need to isolate a field of physics dealing exclusively with physical relations in the natural environment, soil, water, air, plants, animals, raw materials of plant and animal origin, and food products. This field – agrophysics – should have its own conceptual system covering a specific field of study.

Agrophysics studies the ecosystem and biological objects that participate in the food production process, which are processed by human activity and whose mathematical, physical, and chemical attributes are described with the use of scientific methods. Agrophysics could further the development of food research by:

- Introducing universal standards applicable to biological objects for food production
- Promoting the development of high-precision research methods investigating the phenomena and properties encountered in the food production process
- Describing physical processes in food production
- Examining the physical properties of farming produce used for food processing
- Investigating mutual relations in the natural environment relating to food production
- Designing new methods that restrict the degradation of the environment where raw materials and food are produced
- Monitoring and storing data on changes in physical quantities characteristic of raw materials and food products during processing
- Developing mathematical models of the processes observed in biological objects that are marked by high variability and anisotropicity during food production

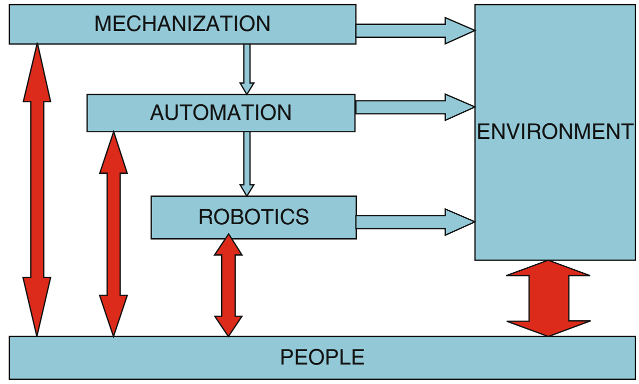
- Developing advanced measuring systems supporting fast and precise measurement of physical properties in automated food production
- Improving physical methods in the area of food production
- Developing new methods for evaluating food quality and safety

Physics supports agricultural engineering that deals mainly with soil – machine – plant systems and breeding animals, as well as food engineering, which investigates the relationships between farming produce and machines, and machines and food products. The relationship between physics, agricultural engineering and food engineering is based on the supply of data from physical experiments for developing new production technologies, preserving and storing food, designing machines, devices, research methods, measuring equipment and apparatuses. Physics will have a growing role in agricultural and food engineering because the progressing drop in employment levels in the farming sector will force farming corporations and local food producers to modernize and expand their resources.

Trends in the development of agricultural machinery and food machinery

There will be a growing demand for new technologies yielding high quality raw materials and food products (Semos, 2004). The interest in new-generation machines will rise. New computer-aided design solutions will shorten design time and cut the relevant costs, while significantly enhancing the quality of the end product. 4D computer-aided design which, in addition to 3D modeling principles, accounts for the time factor, will enable scientists not only to model but also to simulate the kinematics of mechanical motion and the dynamics of changes taking place in machines, raw materials, and food products over time.

According to the National Academy of Engineering, the quality of life in the twentieth century improved dramatically owing to technological progress in areas such as electrification, the invention of mechanical vehicles and airplanes, potable water networks, electronics, radio, television, computers, telephones, paved roads, spaceships, the Internet, medical technology, crude oil processing, lasers and optical fibers, nuclear technology, and state-of-the-art materials. Living standards also improved owing to farming mechanization (ranked 7th), air-conditioning and cooling (ranked 10th) and household equipment (ranked 15th). The twentieth century brought the mechanization era to a close. The current level of technological process supports the construction of machines that may successfully replace human labor. The twenty-first century will witness the development of scientific fields such as information technology, biotechnology, and mechatronics, which will automate and robotize production processes, including farming and the food industry (Figure 1). Physics will play an important role in this process. Highly industrialized countries are entering a new phase of technological advancement marked by automation and robotization of production and services (Liu et al., 2009). Efforts must be made to ensure this progress does not have adverse consequences for the natural environment, which is of fundamental importance for the quality of life on Earth.

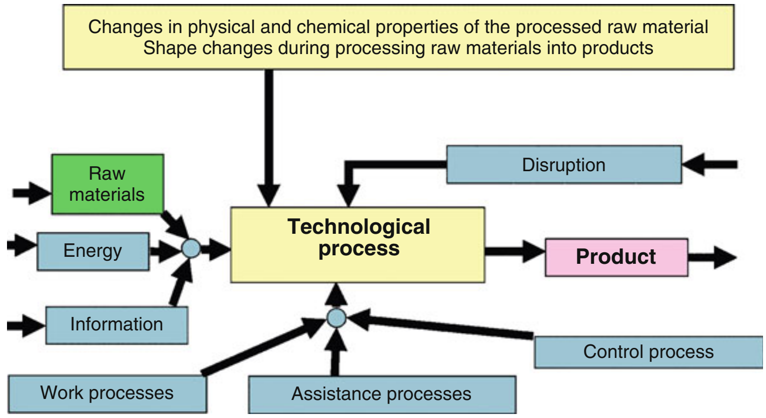


Agriculture and Food Machinery, Application of Physics for Improving, Figure 1 Stages of technical modernization in agriculture and the food processing industry.

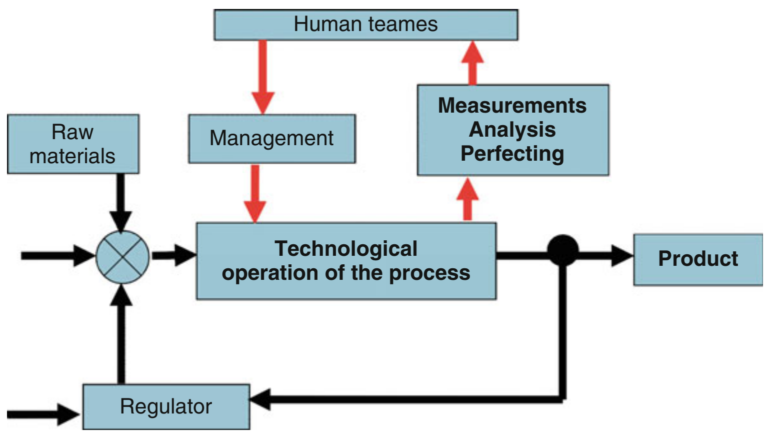
The challenges presently faced by physics, agricultural and food engineering involve rational and pragmatic needs analyses, systematic research, the development of theoretical systems based on the results of scientific experiments and observations, and expanding and building a reliable knowledge base with practical implications leading to the implementation of new concepts. A reliable knowledge base delivers practical results and contributes to an improvement in the quality of life. Scientific progress in new farming and food processing technologies can be used to ensure social demands and can be implemented on a mass scale.

In the process of dynamic civilizational development, science should be independent and free of any political influences in order to deliver unbiased solutions at every stage of development of new technologies and machines. Above all, scientific advancement should support the establishment of a sustained relationship between artificial systems, the natural environment, and man (Arvanitoyiannis et al., 2000; Ravertz, 2002). In designing optimal design, decisions must be taken, having a serial structure which affects the quality of the proposed agricultural machinery and food machinery. This process has very serious consequences as it determines the final quality of farming and food processing machines. Scientific teams designing farming and food processing machines rely on data that deliver information on the physical and chemical properties of soil, plants, animals, and end products (Mieszkalski, 1997). Physics must fill the existing knowledge gaps in a structured way to support technology process design and then the machine design (Figure 2).

A technological process is a dynamic system where the set of input data accounts for raw materials, energy, and



Agriculture and Food Machinery, Application of Physics for Improving, Figure 2 Block diagram of a technological process.



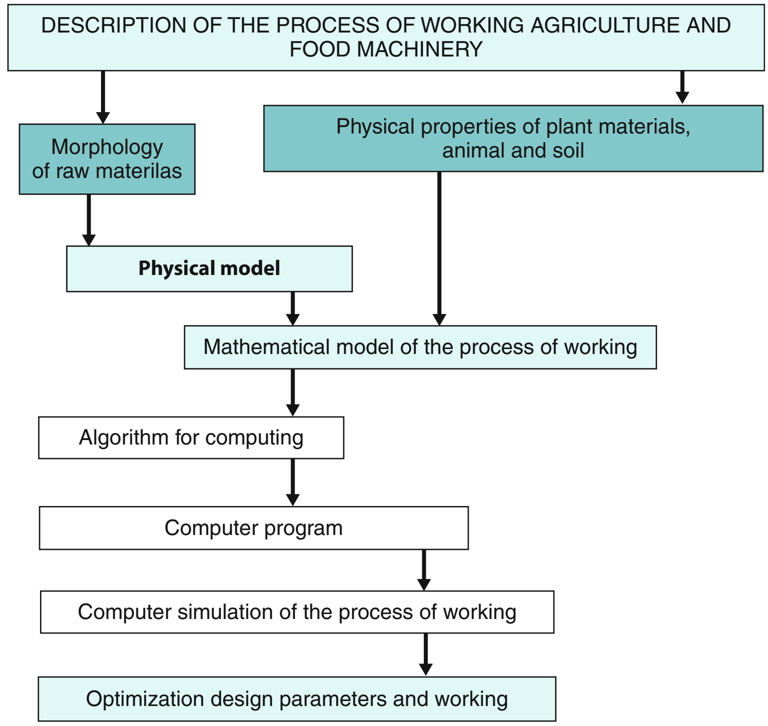
Agriculture and Food Machinery, Application of Physics for Improving, Figure 3 Block diagram of a technological process operation.

information, and the set of output data comprises end products and waste. In the initial design phase, the technological process and the process line supplying farming and food processing machines have to be thoroughly evaluated to guarantee the highest quality of the end product. Scientists should develop structural solutions to search for appropriate solutions in the design process of machines farming and food processing machines.

A well-designed process that accounts for economic, ergonomic, environmental, and social criteria consists of a series of activities that modify the physical and chemical parameters and the shape of the processed materials, and facilitate the search for new structural solutions. A thorough examination and a detailed description of the technological process should underlie all research efforts in physics, agricultural engineering, and food processing engineering (Figure 3).

Every working process in the food processing industry comprises many complex and interconnected factors. Their impact on the technological process is determined by the physical condition of the processed plant and animal material as well as the kinematic and dynamic parameters of the processing system. An algorithm describing the technological process of a machine is presented in Figure 4 (Mieszkalski, 1998a). The food production process involves physical events and phenomena. A physical phenomenon is an event during which the form of a biological object is transformed by modifying its physical properties. The occurrence of a physical phenomenon requires electrical, magnetic, gravitational and particle interactions as well as friction. A phenomenon is a unitary event, an existing fact. The physical state of a material object embodies its quality, form, level, quantity, number, and location at a given time. The technological process of a farming and food processing machine encompasses a number of constituent processes, which form a sequence of actions and measures required to achieve the planned goal.

In the technological process of a machine, the processing of raw materials into food products involves



Agriculture and Food Machinery, Application of Physics for Improving, Figure 4 Block diagram of a farming machine's technological process.

the modification of their physical and chemical properties. Those changes and their course have to be taken into account at the stage of designing the working process as the quality of the end product can be modified during that phase. An analysis of the food production process relies on the results of research involving a verified mathematical model that constitutes a formal basis for the computer-aided simulation of that process. A computer simulation is a method of investigating an empirical system which, in view of the objective of modeling, may replace natural experiments in the process of acquiring information on the efficacy of the analyzed technical system. This research method will have a growing role in the design of farming and food processing machines. The precision of computer simulations is determined mainly by the degree of accuracy delivered by the mathematical model, the description of input data, errors, and the applied simplifications. Physical sciences are of utmost importance in this type of research. By selecting the appropriate research methods, physics theories and other cognitive instruments, scientists are able to explain how physical quantities affect vital changes in the physical properties of raw materials and food products. Computer simulations involve the use of software based on algorithms that allow the user to generate a history of raw material stocks and monitor the progress in machine construction. It should be noted that a simulated working process is merely an approximated representation of the real process rather than its faithful replication. By relying on computer simulations as a research method in designing technological processes and machines, scientists select a sequential system of events and simulate elementary processes in a given order. The majority of simulations rely on the fixed time-step method and the discrete event method. In the fixed time-step method, events take place in steps that increase by a fixed time increment. In the discrete event method, a growing time increment is attributed to the next event. The results of a computer simulation are verified experimentally.

Technical progress will also modify the structural solutions applied to farming equipment. There will be growing demand for new-generation farming machines equipped with satellite navigation, board computers, and feedback control systems. GPS navigation and the development of computer technology will create new prospects for intelligent farming machines. The operating conditions and the requirements imposed on such equipment will be determined by physics and agricultural engineering. We must create a design-effective system for controlling and managing agricultural production while ensuring that the technical advancements in farming directly contribute to the quality of the end product. In the near future, precision farming will become the leading branch of agriculture. Many tractors, fertilizer distributors, seeding machines, and combines for harvesting cereal and root crops are equipped with electronic and data transmission systems. Farming and food processing machines are turning into complex mechatronic systems. We are witnessing the rapid development of remote control solutions for farming machines supplying raw materials for the food production industry. A machine that is a programmable mechatronic system (Mieszkalski, 1998a) equipped with sensors receives signals from the environment during the working process. Those signals are processed and interpreted in view of the existing situation and possible control errors, after which they are transmitted to the machine's steering unit to maintain adequate working parameters and optimize the movement of working elements. In systems equipped with feedback control, the operator is no longer required to directly control the machine's operating parameters. The operator enters into a relationship with a mechatronic system by inputting system data and controlling processed output data. In a mechatronic system, sensors generate signals on the physical quantities of a working process that involves the machine and raw materials. After processing, the signal is transmitted to the steering unit, which modifies working parameters accordingly. Physics also aims to devise new solutions for sensors analyzing the physical condition of the processed plant and animal raw materials. One of such examples is the electronic nose, which monitors changes in the aroma of farming produce during storage. This solution involves artificial neural networks that have been trained to detect the age of grain (Zhang and Wang, 2008).

The contemporary GIS technology with 3D spatial data and the option of developing numerical terrain and field maps, crop maps, and soil nutrient maps are the stepping stone on the road to developing remotely controlled machines (Karimi et al., 2008). Technological progress in farming production will further the development of sensors for measuring and, when coupled with the possibilities offered by IT systems, monitoring the characteristic properties of the soil, plants, and the atmosphere. Physics and agricultural engineering will propose a variety of new solutions in the area of machine and sensor construction.

Tractors have played and continue to play a vital role in farming. Their horsepower ranges from 30 to around 650. Tractors with the highest output weigh around 20 t. The dynamic growth of physics, farming, biological, technical, and IT sciences has visibly furthered the development of the tractor industry. The leading manufacturers of farming equipment have been conducting intensive research into the design of driverless tractors. The most important considerations that have to be taken into account in the design of modern tractors are steering systems, control systems as well as ergonomic solutions (Drakopoulos and Mann, 2008). Similar problems have to be tackled as regards other types of farming and food processing equipment.

The requirements imposed on agricultural machines will change owing to the vast variation in the size of farming areas. The main problem is the selection of production technologies and machines that would not lead to the degradation of soil and the natural environment. Heavy-duty, self-propelled farming machinery delivering a high productive yield is developed to cater to the needs of large commercial farms. The problem of excessive pressure exerted on soil by farming equipment, in particular heavy-duty machines, has not been solved to date. Designers are short of ideas for building an innovative drive system. The existing choice is limited to wheel and caterpillar drive systems (Figure 5). Farming machinery is becoming heavier, and it exerts a growing load on the soil. The intensive use of contemporary machines leads to soil rolling, structural damage, and degradation. Machines weighing 20 t, mostly potato harvesters, exert a highly negative effect on loosened soil by compacting it excessively (Figure 6). Vehicles transporting the harvested crops to the place of storage also contribute to soil damage.

Soil fragmentation and structural damage caused by rotary and swirl harrows are also a serious problem (Figure 7). Disk blades of rotary and swirl harrows used in simplified farming systems produce a cycloidal motion and exert an uneven effect on the soil (Figures 8 and 9) (Mieszkalski, 1998b). There are no effective solutions protecting harrows against damage when the disk blade hits a hard obstacle, such as a rock.

Global climate change will have a growing impact on agriculture. In many regions, milder winters marked by fewer days with below-zero temperatures and less snow undermine the purpose of deep fall plowing. A detailed analysis of the effect of plowing on the dynamics of soil changes in view of climate change will contribute to the search for new cultivation technologies, including methods that do not rely on plows.

The challenge for designers is to develop new technologies to minimize the adverse effects of chemicalization of

Agriculture and Food Machinery, Application of Physics for Improving, Figure 5 Wheels and caterpillars in farming machines.

Agriculture and Food Machinery, Application of Physics for Improving, Figure 6 Excessive soil compaction caused by farming machines.

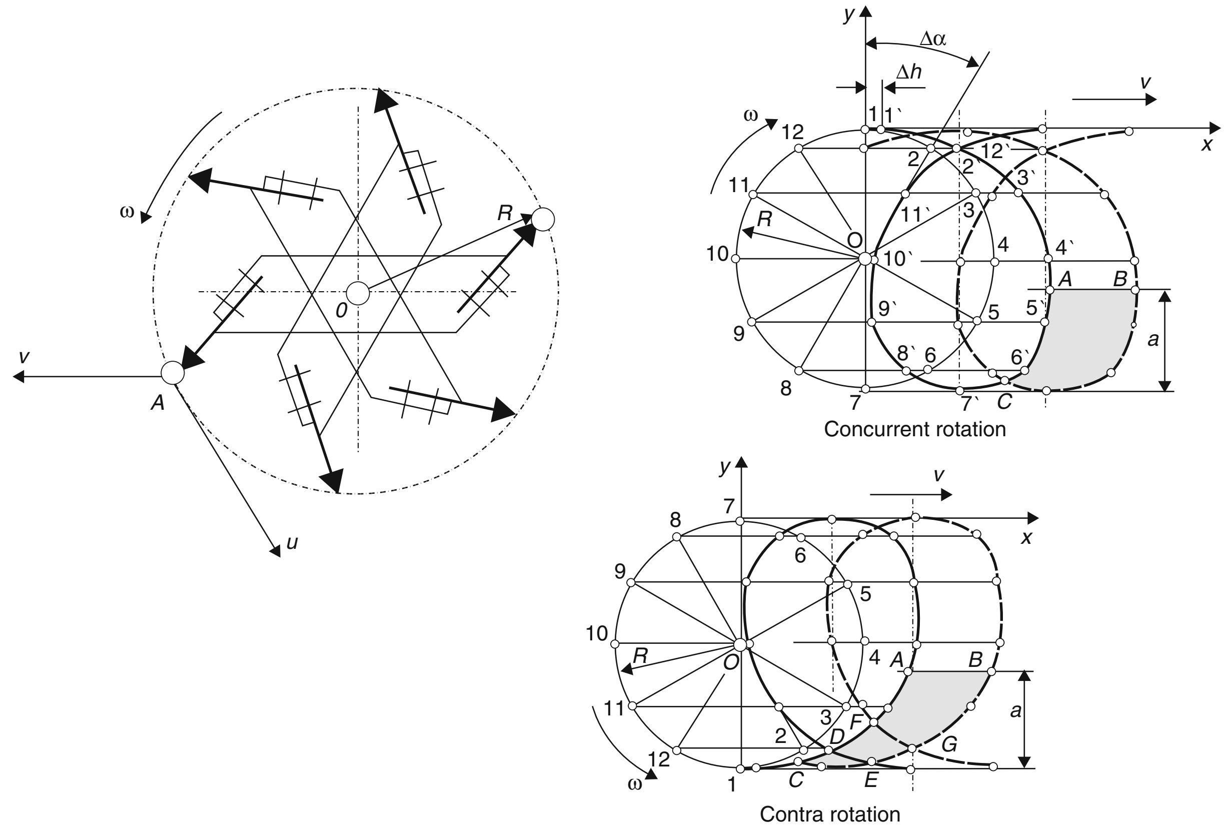
Agriculture and Food Machinery, Application of Physics for Improving, Figure 7 Harrow rotor's effect on the soil.

food products and production in general. We must prevent environmental degradation of not reducing the standards of living. Environmental contamination caused by physical, chemical, and biological factors applied in the growing of farm produce and the food processing industry poses a mounting problem. The production of wheat grain, for example, involves around six chemical treatments. Designers are faced with the challenge of inventing machines and equipment that support such technological processes.

The problem of excessive chemicalization is also encountered in the food processing industry. The applied pesticides and mineral fertilizers systematically introduce toxic substances to the soil across large areas. An interesting alternative is the use of optical sensors in electronic weed control systems, which selectively spray herbicides on crop plantations (Celen et al., 2008). The failure to observe waiting periods makes the soil, plants, seeds, and crops susceptible to the deposition of toxins. As a result, harmful substances enter the food chain of humans and breeding animals. Despite the application of precision farming methods (soil fertility maps, board computers), the disks of fertilizer distributors do not spread the fertilizer evenly across the field. There is a dire need for new methods of protecting plants against weeds and pests that do not rely on chemicals and minimize environmental contamination. Precision agriculture offers such a solution. New methods are also needed for the early detection of disease sources and pest development stages to support the quick implementation of treatment methods that do not involve chemicals. Image analysis coupled with precision pesticide application is an innovative option. For the needs of farming production, chemicals should be regarded as medical treatment, not a method of increasing crop yield that disregards quality considerations. Product chemicalization in the food processing industry adds to the problem. Appropriate solutions should be offered by science, in particular agrophysics, agricultural engineering, and food engineering.

Combines for harvesting grain, potatoes, carrots, and beets are part of a rapidly developing market of farming machines. Advanced solutions are implemented in the group of combine harvesters whose main working elements have not been upgraded in the past 150 years. The introduced modifications include double-rail axial threshing mechanisms, double-cylinder threshing units, straw shaker supports, belt conveyors instead of worm conveyors in combine headers, laser remote control systems for guiding combines, and many other solutions. In designing, it is important to ask and seek answers for questions, for example: Is a combine harvester the ultimate solution? Should threshing take place in the field? How can the seed ripening period be prolonged? Can grain harvesting be mechanized or automated with the use of modern technology that replaces combines and economizes the harvesting process? Modern combine harvesters are equipped with board computers for controlling and monitoring the machine's working parameters and the quality of harvesting operations. Satellite navigation systems support the generation of digital yield maps (Fulton et al., 2009). Combine harvesters are also equipped with vision systems comprising several video cameras outside the machine for surveying the harvested area.

By-products of the farming process, such as straw, are also an important consideration in view of the changes taking place in agricultural practice. Straw is pressed in the field, and its density reaches around 180 kg m^{-3}. Various structural solutions for straw presses are available. Presses are equipped with control units for monitoring the compacting process and its working parameters. Straw used as an energy resource is compacted into pellets with density of up to 1,400 kg m^{-3} as well as into briquettes



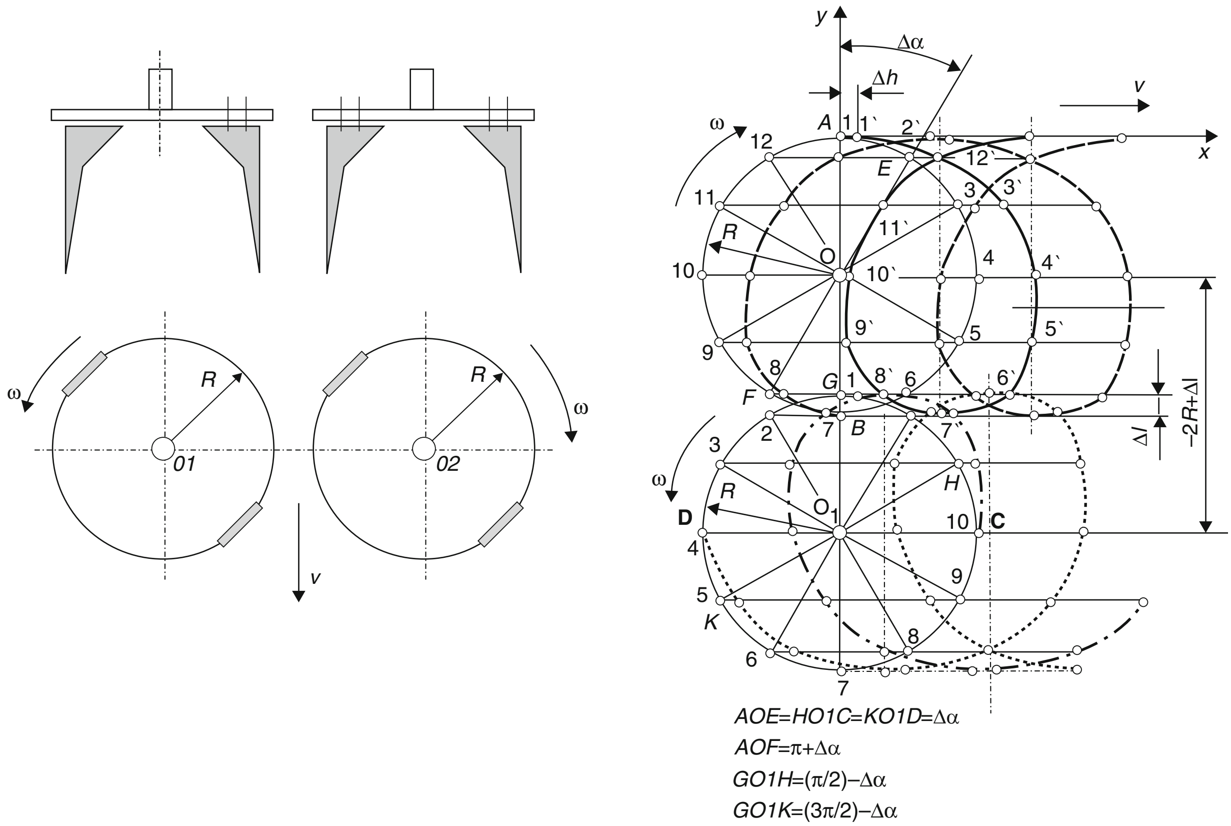
Agriculture and Food Machinery, Application of Physics for Improving, Figure 8 Motion trajectory of rotary harrow disk blades.

with density of around 700 kg m^{-3}. New briquetting techniques will soon be developed with the involvement of, for example, straw rolling, to produce briquette density of 500 kg m^{-3} or higher.

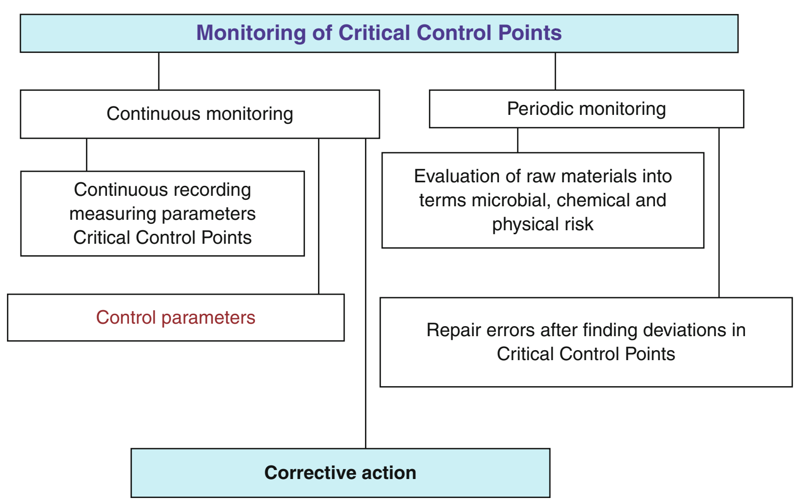
Significant progress is also noted in numerical methods for data processing and process virtualization in farming and food production. Production lines with a feedback control signal are implemented in food processing plants.

Production of raw materials and food processing technologically must be adapted to quality management requirements. Food processing plants implement HACCP systems for analyzing biological, chemical, and physical threats and for measuring and monitoring critical parameters that significantly affect food safety and quality. Risk evaluation in food production poses another challenge. The task of food engineering, agricultural engineering, physics, and other sciences is to devise methods ensuring the safe application of chemicals, food additives, and bioengineered foods. The selection of adequate risk evaluation methods in the food industry is a difficult process because food products contain a high number of ingredients, which form a variety of combinations (Brock et al., 2003; Blaha, 2001). Biotechnology plays an increasingly important role in food production, and it involves the modification of the natural ingredients of foodstuffs (Taylor, 2003). Various branches of science, including food engineering, agricultural engineering, and physics, search for effective and transparent production methods that guarantee the safety of bio-engineered products that have not been mass produced to date. Food safety systems monitor the value of critical parameters at control points of the production line to ensure that qualitative requirements are met. Critical parameters are monitored continuously and periodically with the use of principles of mathematical statistics (Figure 10). Continuous monitoring supports production with a feedback control signal. The production process is observed by experts on computer screens. Many operations are performed on fully automated lines. Automated systems are tested on grafted tomato seedlings for monitoring the external features of plants during growth (Chiu et al., 2008). Camera vision systems are used to classify farming produce by determining its physical properties such as length, diameter, curvature, flower color, flower size, and surface damage (Chong et al., 2008).

Robots are increasingly often used in food production. New robots equipped with complex kinematic systems, sensory devices, vision cameras, and complex control algorithms have a growing number of applications in the food industry. They are used for object grabbing with pressure control, transporting, packaging, palletizing, production line work (e.g., carcass dressing), cooling plant



Agriculture and Food Machinery, Application of Physics for Improving, Figure 9 Motion trajectory of swirl harrow disk blades.



Agriculture and Food Machinery, Application of Physics for Improving, Figure 10 Block diagram of monitoring physical quantities and working parameters during a technological process.

operations, etc. Greenhouses were the first farming sites to introduce mobile robots (González et al., 2009).

In an era marked by dynamic changes in the global culture, which is becoming dominated by politics, free market principles, consumerism, temporary solutions, and the flood of information that dulls our senses, scientists have to ask precise questions and search for the answers. Modern technology and economy cannot replace quality. The most urgent task for physics, agricultural and food engineering is the search for effective production methods that guarantee the highest quality of both raw materials and the end product. The above will be determined by their willingness to tackle complex problems. In an era marked by growing production, higher work efficiency, and soaring competition, we need to reflect and develop a rational approach to technological progress in line with the following motto: “to produce, but without doing harm to nature and mankind”.

The process of building contemporary machines relies on data from various fields of science. Physics plays an important role in this process by searching for new structural materials, methods for determining their physical properties, and the displacement of elementary particles under the influence of internal and external forces. As regards the design of farming and food processing machines, the role of physics is to find new mechanisms and new methods of kinematic and dynamic analyses. The determination of trajectory, speed and acceleration, and the search for motion that meets a given set of kinematic conditions are very important considerations in the kinematics of mechanisms. Dynamics is also of paramount significance in the construction of farming and food processing machines as it determines changes in force over time during operation and the correlation between motion and the forces acting on different parts of a machine. The variability of load applied to the working elements of a machine results from the non-homogeneity of the processed biological material. Substrate variability and changes in its spatial configuration affect the load applied to the working elements of a farming machine. The elements of farming and food processing machines are subjected to complex, often nonlinear load. The search for methods of anticipating the behavior of machines and their subassemblies under the influence of variable and stochastic load poses a serious challenge for contemporary physics. New scientific theories in the field of nonlinear system dynamics need to be formulated. The working process of farming and food processing machines is the result of many complex relations between the machine, its operator, and the operating environment. Physics should play a fundamental role in the search for relations that are optimal for machines, man, and the environment.

Owing to the vast diversity of farming and food processing machines, the role of physics in the process of designing and modifying all models cannot be described in detail. In this group of machines, a number of work processes have a universal character. The key processes in obtaining plant materials for food production are: soil engaging operations, seedbed preparation, inter-row tillage, spreading of organic and mineral fertilizers, distribution and planting of seeds, seed-potatoes and seedlings, formation of liquid droplet streams for plant protection and stream distribution on plant surface, cutting plant material, reeling, gathering, shaking, raking and transporting stem material, crushing stem material, threshing, separating, and transporting crops. The following general processes take place in food production: shredding, separation, liquid flow, filtration, pressing, forming, liquid squeezing, movement of solids in liquid, movement of liquids in liquid, agglomeration, hulling, peeling, drilling, cleaning, germination, polishing, removing inedible parts, gravitational and centrifugal separation, straining, settling, classification, transport, mixing and dosing, cleaning, packaging, drying, distilling, extracting, leaching, cooling, freezing, heat processing, and pressure processing. The design of farming and food processing machines relies heavily on data on the physical and chemical properties of soil, raw materials, food products, technological process, and the design methodology. Physics contributes vast amounts of information on the physical properties of soil, raw materials, and food products, and it describes physical phenomena that occur when raw materials are processed into foodstuffs.

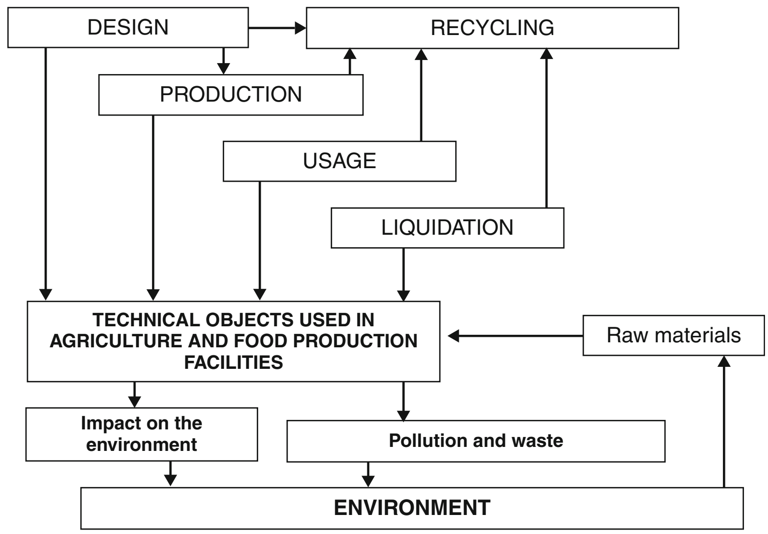
Designers building farming and food processing machines have to account for all stages in the machine’s life cycle (Figure 11). The quality of serially structured design decisions determines the usable properties of machines, the safety of operators, and the impact of machines on the natural environment. Farming machines are closely interrelated with the environment throughout their entire working life. The natural environment supplies nonrenewable resources for the production of structural materials. The manufacture, use, and scrapping of farming and food processing machines is a source of waste and pollution that has a highly adverse effect on man and the environment (Park and Kim 2009a, b, c). New solutions are needed for recycling used materials to limit or eliminate the disposal of worn-out machines and lower the demand for new resources. Physical sciences will support the development of new methods for applying recycled materials in the production of brand-new items and protecting the natural environment against the hazards posed by other scientific inventions, such as gamma ray and X-ray radiation.

Above all, the main goal of practical inventions delivered by research in physics should be the well-being of humans and the protection of the natural environment.

Summary

Many problems still await a solution. The greatest challenges involve the standardization of farming sites, determination of the spatial and structural attributes of soil, raw materials and products, protection of food products against negative factors, modeling and computer-aided simulation of food production processes, developing effective methods for evaluating food quality, designing new measuring systems for monitoring, storing and processing data, and effective decision-making at different stages of the food production process.

Use of latest achievements of science is required in studies of physical properties of raw materials and food products. Use of advanced measuring technologies is essential in gaining new information on the raw material and food production. In the production of raw materials



Agriculture and Food Machinery, Application of Physics for Improving, Figure 11 The main stages in the life cycle of a farming and a food processing machine and its impact on the natural environment.

increasing role plays precision farming. Automatization with robots use is developing rapidly. Further interdisciplinary research is needed to achieve safe food product, both produced on an industrial scale and in small manufacturing plants. It is important to search for new food products, and new food technologies in mass and local production. Modern machines should concerned new technologies of food preservation, conservation and food packaging considering positive influence on peoples' health.

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Cross-references

Agrophysical Objects (Soils, Plants, Agricultural Products, and Foods)
Agrophysical Properties and Processes
Databases on Physical Properties of Plants and Agricultural Products
Mechanical Resilience of Degraded Soils
Monitoring Physical Conditions in Agriculture and Environment
Organic Farming, Effect on the Soil Physical Environment
Physical Degradation of Soils, Risks and Threats
Physical Properties of Raw Materials and Agricultural Products
Physics of Plant Nutrition
Precision Agriculture: Proximal Soil Sensing
Soil–Plant–Atmosphere Continuum
Soil–Wheel Interactions
Standardization in Agrophysics
Tillage Erosion

AGROFORESTRY SYSTEMS, EFFECTS ON WATER BALANCE IN CROPPING ZONE

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Definition

Many definitions were formulated within last few decades. One of the last definitions was made up by World Agroforestry Centre (ICRAF) in 1993:

Agroforestry is a collective name for land use systems and practices in which woody perennials are deliberately integrated with crops and/or animals on the same land management unit. The integration can be either in a spatial mixture or in a temporal sequence. There are normally both ecological and economic interactions between woody and nonwoody components in agroforestry.

Agroforestry is a land use system that allows for the concurrent production of trees and agricultural crops from the same piece of land (Gordon and Newman, 1997).

Agroforestry should be considered as a dynamic, ecologically based, natural resource management system that, through the integration of trees in farm and rangeland, diversifies and sustains production for increased social, economic, and environmental benefits (Leakey, 1996).

History

It has a rich history of development and has been practiced in some parts of the world for more than 6,000 years. Much recent research into agroforestry has been carried out in the tropics and within the context of developing nations, where land shortages brought about by the rapid growth in population demand that efficient production systems for both wood and food be developed and enhanced.

Agroforestry is an age-old practice throughout the world, but its recognition as a science is nearly 5 decades old. For example, during the Han Dynasty (206 BC to AD 220), administrators recommended that forests be developed to accommodate livestock husbandry and crops, according to varying site conditions. Qi Min Yao Shu reported that during the sixth century, the Chinese scholar tree (*Sophora japonica*) was planted with hemp for the purpose of increasing hemp growth and to improve the form of trees for future roadside plantations (Gordon and Newman, 1997).

In mid-1970s, the International Center for Research in Agroforestry (ICRAF) was created in response to a visionary study in the mid-1970s led by forester John Bene of Canada's International Development Research Centre (IDRC). The study coined the term "agroforestry" and called for global recognition of the key role trees play on farms. This initiation led to the establishment of ICRAF in 1978 to promote agroforestry research in developing countries.

During the 1980s, ICRAF operated as an information council focused on Africa. It joined the Consultative Group on International Agricultural Research (CGIAR) in 1991 to conduct strategic research on agroforestry at a global scale, changing its name from Council to Centre. After joining the CGIAR, the Centre explicitly linked its work to the goals of the CGIAR – reducing poverty, increasing food security, and improving the environment – through two means: overcoming land depletion in smallholder farms of subhumid and semiarid Africa, and searching for alternatives to slash-and-burn agriculture at the margins of the humid tropical forests. In implementing this strategy, the Centre expanded into South America and Southeast Asia while strengthening its activities in Africa.

Within 1990s, ICRAF continued the process of institutional transformation by developing a science culture, building excellent research facilities, and doubling its financial and human resources by 1996. The Centre formally adopted an integrated natural resource management framework for all of its work, and institutionalized its commitment to impact by creating a Development Group dedicated to moving research results onto farmers' fields.

In 2002, the Centre acquired the brand name the "World Agroforestry Centre"; however, the "International Centre for Research in Agroforestry" remains our legal name. The new name reflects the fact that the Centre is now recognized as the international leader in agroforestry research and development. Realistically, however, the Centre cannot possibly provide expertise on all conceivable dimensions of agroforestry – nor do we wish to do so. There are advantages to specialization, which is why the Centre engages in strategic alliances with a range of other institutions. Some of these partners are centers of scientific excellence in specific topics of relevance to agroforestry; others specialize in the effective delivery of research results to farmer's fields (Technical Advisory, 1993).

Agroforestry

The "art" of agroforestry has evolved over centuries; agroforestry as a formalized approach to land use is more recent. Agroforestry is promoted on the basis that it can provide biological, economic, and social advantages. ICRAF's Strategic Plan (Technical Advisory, 1993) states "resource-poor rural households benefit from improved soil fertility coming from the introduction of nitrogen-fixing trees in enriched fallows or through interplanting; they gain additional income through sale of tree products such as fruit or timber; and gain improved food security associated with the way the perennial component of agroforestry systems extends the season when green fodder and food supplies are available. The latter benefit has significant implications for the nutritional vulnerability of the poorest groups, especially women and children. At the same time, the quality of the environment is maintained through the maintenance of biological diversity, preservation of water catchments and soil quality, and a halt to the net loss of forested land."

Agroforestry combines agriculture and forestry technologies to create more integrated, diverse, productive, profitable, healthy, and sustainable land-use systems. It means that trees are intentionally used within agricultural systems. Knowledge, careful selection of species, and good management of trees and crops are needed to maximize the production and positive effects of trees and to minimize negative competitive effects on crops.

Agroforestry must satisfies four requirements: (1) it is a form of multiple cropping, (2) at least one component is a woody perennial, (3) the component interacts biologically, (4) at least one of plant species is managed for forage, annual or perennial crop production (Somarriba, 1992). Agroforestry must be compatible with local sociocultural practices and serve to improve living conditions in the region.

Agroforestry systems can be advantageous over conventional agricultural and forest production methods through increased productivity, economic benefits, social outcomes, and the ecological goods and services provided.

There are five basic types of agroforestry practices today: alley cropping, silvopasture, windbreaks, riparian buffers, and forest farming. Within each agroforestry practice, there is a continuum of options available to landowners depending on their own goals (e.g., whether to maximize the production of interplanted crops, animal forage, or trees).

Alley cropping

Alley cropping, sometimes referred to as "sun systems," is a form of intercropping, and can be applied by farmers as a strategy to combat soil erosion, to increase the diversity of farmland, as a means for crop diversification and to derive other integrated benefits. In this practice, crops are planted in strips in the alleys formed between rows of trees and/or shrubs. The potential benefits of this design include the provision of shade in hot, dry environments (reducing water loss from evaporation), retention of soil moisture, increase in the structural diversity of the site, and wildlife habitat. The woody perennials in these systems can produce fruit, fuelwood, fodder, or trimmings to be made into mulch.

Alley cropping involves growing crops (grains, forages, vegetables, etc.) between trees planted in rows. The spacing between the rows is designed to accommodate the mature size of the trees while leaving room for the planned alley crops. When sun-loving plants like corn or some herbs will be alley cropped, the alleyways need to be wide enough to let in plenty of light even when the trees have matured.

Like all integrated systems, alley cropping requires skillful management and careful planning. Both the crop and the trees have requirements that sometimes necessitate tradeoffs between them. The design must allow sufficient room for the equipment needed to service each enterprise.

Silvopasture

Silvopastures combine livestock grazing on forage crops or pastures within actively managed tree or shrub crops. Cattle, sheep, and goats are the most common livestock incorporated into silvopasture systems and they may be deployed entirely within a private farm/woodlot silvopasture or through collaborative arrangements between forest licensees and livestock producers on public lands. Tree and pasture combinations are called *silvopastoral agroforestry*. Hardwoods (sometimes nut trees) and/or pines are planted in single or multiple rows, and livestock graze between them. Although both the trees and the livestock must be managed for production, some systems emphasize one over the other. Usually, in the early years of establishment, crops or hay are harvested from the planting. Grazing generally begins after 2 or 3 years, when the trees are large enough that the livestock cannot damage them. In other instances, tree tubes and electric fencing protect the young trees, and grazing begins immediately.

Grazing livestock on silvopasture eliminates some of the costs of tree maintenance. With good grazing management, for example, herbicides and mowing may become unnecessary. Grazing also enhances nutrient cycling and reduces commercial fertilizer costs; the animals remove few nutrients, and their waste is a valuable input for the trees. Well-managed grazing will increase organic matter and improve soil conditions. However, controlling the number of animals per area, limiting the number of days those animals remain on each site, and avoiding compaction are critical for a successful silvopasture system.

Windbreaks or shelterbelts

Extensive research on windbreaks, also called *shelterbelts*, has been carried out in many countries. Trees are planted in single or multiple rows along the edge of a field to reduce wind effects on crops or livestock. Windbreaks have been shown to reduce wind impact over a horizontal distance equaling at least ten times the height of the trees. Wind and water erosion are reduced, creating a moist, more favorable microclimate for the crop. In the winter the windbreak traps snow, and any winter crops or livestock are protected from chilling winds. Beneficial insects find permanent habitat in windbreaks, enhancing crop protection.

Although the trees compete for available water along the edges between the windbreak and the crop rows, potentially reducing crop yield near the windbreak, the net effect on productivity is positive. In fact, even on land that is well suited for high-value crops, a windbreak can increase the crop yield of the entire downwind field by as much as 20%, even when the windbreak area is included in the acreage total.

Windbreaks can be designed specifically for sheltering livestock. Studies have shown the economic advantages of providing protection from wind chill, a major stress on animals that live outside in the winter. Reduced feed bills, increases in milk production, and improved calving success have resulted from the use of windbreaks. Besides providing protection to crops and livestock, windbreaks offer other advantages. They benefit wildlife, especially by serving as continuous corridors along which animals can safely move.

Any tree species can be used in a windbreak. However, deciduous species, even in multiple rows, will lose effectiveness when they lose their leaves. For year-round use, some of the species selected should be evergreen. Fast-growing trees should be included; it is best to plant deep-rooted, noncompetitive species along the edges. Regular deep chisel plowing along the edges will keep roots from spreading into the crop rows. If some of the trees are harvested periodically, replacements can be planted, establishing a long-term rotation.

Riparian buffers and integrated riparian management

Riparian buffers are managed forest and shrubs belts in areas bordering lakes, streams, rivers, and wetlands. Integrated riparian management systems are used to enhance and protect aquatic and riparian resources as well as generating income from timber and non-timber forest products. Similar to shelter and timberbelts, integrated riparian management systems can employ a wide variety of tree and shrub species, with specific plantings tailored to suit the specific growing conditions and production opportunities.

Trees, grasses, and/or shrubs planted in areas along streams or rivers are called *riparian buffers* or *filter strip*s. These plantings are designed to catch soil, excess nutrients, and chemical pesticides moving over the land's surface before they enter waterways. Such plantings also physically stabilize stream banks. On cropland that is tiled to improve drainage, polluted water can flow directly into streams; constructed wetlands installed in the buffers can capture and clean this drainage water before it enters the stream. Shading the water keeps it cooler, an essential condition for many desirable aquatic species. Buffer strips also provide wildlife habitat and can be managed for special forest products.

Forest farming and special forest products

Forest farming, also known as "shade systems," is the sustainable, integrated cultivation of both timber and non-timber forest products in a forest setting. Forest farming is separate and distinct from the opportunistic exploitation – wild harvest of non-timber forest products. Successful forest farming operations produce mushrooms, maple and birch syrup, native plants used for landscaping and floral greenery (e.g., salal, sword fern, bear grass, cedar boughs, and others), medicinal and pharmaceutical products (e.g., ginseng, goldenseal, cascara, or yew bark), wild berries, and fruit. When a natural forested area is managed for both wood products and an additional enterprise, it becomes an agroforestry system. Besides producing saw timber and pulpwood, woodlands can generate income from many other products. Established forests offer many non-timber "special forest products" that contribute to cash flow without requiring the one-time harvest of old trees. For example, landowners can manage established woods to encourage naturally occurring patches of berries or bittersweet. Or they might plant understory crops adapted to the forest type and climate. Growing mushrooms on logs is another, more labor-intensive, possibility; a canopy of either hardwoods or pine will provide the shade needed to maintain moisture for fruiting.

Benefits

Agroforestry practices may also be employed to realize a number of other associated environmental services, including

- Carbon sequestration
- Odor, dust, and noise reduction
- Wastewater or manure management (e.g., utilizing urban wastewater on intensive, short rotation forests for wood fiber production)
- Green space and visual aesthetics
- Enhancement or maintenance of wildlife habitat

Biodiversity in agroforestry systems is typically higher than in conventional agricultural systems. Agroforestry incorporates at least several plant species into a given land area and creates a more complex habitat that can support a wider variety of birds, insects, and other animals. Agroforestry also has the potential to help reduce climate change since trees take up and store carbon at a faster rate than crop plants.

The resulting biological interactions provide multiple benefits, including diversified income sources, increased biological production, better water quality, and improved habitat for both humans and wildlife. Farmers adopt agroforestry practices for two reasons. They want to increase their economic stability and they want to improve the management of natural resources under their care.

Agroforestry practices can increase farmer's annual incomes. Some increases in revenue come from harvesting different tree crops in different seasons. The result is that income and employment are distributed more evenly throughout the year. There are also many other reasons for growing trees on farms, such as the provision of shade for cooler soil temperatures, reduction of soil moisture loss, and protection of the soil from wind and water erosion. Agroforestry systems can reduce the risk of total crop failure. For example, if the viability of one crop is reduced by pest damage or market failure, the farmer can make up for it by harvesting another crop.

Summary

Land-use options that increase resilience and reduce vulnerability of contemporary societies are fundamental to livelihood improvement and adaptation to environmental change. Agroforestry as a traditional land-use adaptation may potentially support livelihood improvement through simultaneous production of food, fodder, and firewood as well as mitigation of the impact of climate change.

To promote well-being of the society, management of multifunctional agroforestry needs to be strengthened by innovations in domestication of useful species and crafting market regimes for the products derived from agroforestry and ethnoforestry systems. Future research is required to eliminate many of the uncertainties that remain, and also carefully test the main functions attributed to agroforestry against alternative land-use options in order to know equivocally as to what extent agroforestry served these purposes.

The ecological integrity of an agroforest is a state of system development in which the habitat structure, natural functions, and species composition of the system are interacting in ways that ensure its sustainability in the face of changing environmental conditions as well as both internal and external stresses (Wyant, 1996).

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Cross-references

Drought Stress, Effect on Soil Mechanical Impedance and Root (Crop) Growth
Evapotranspiration
Irrigation and Drainage, Advantages and Disadvantages
Management Effects on Soil Properties and Functions
Rainfall Interception by Cultivated Plants
Tropical Fruits and Vegetables: Physical Properties

AGROGEOLOGY

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Synonyms

Agricultural geology; Soil science (obsolete)

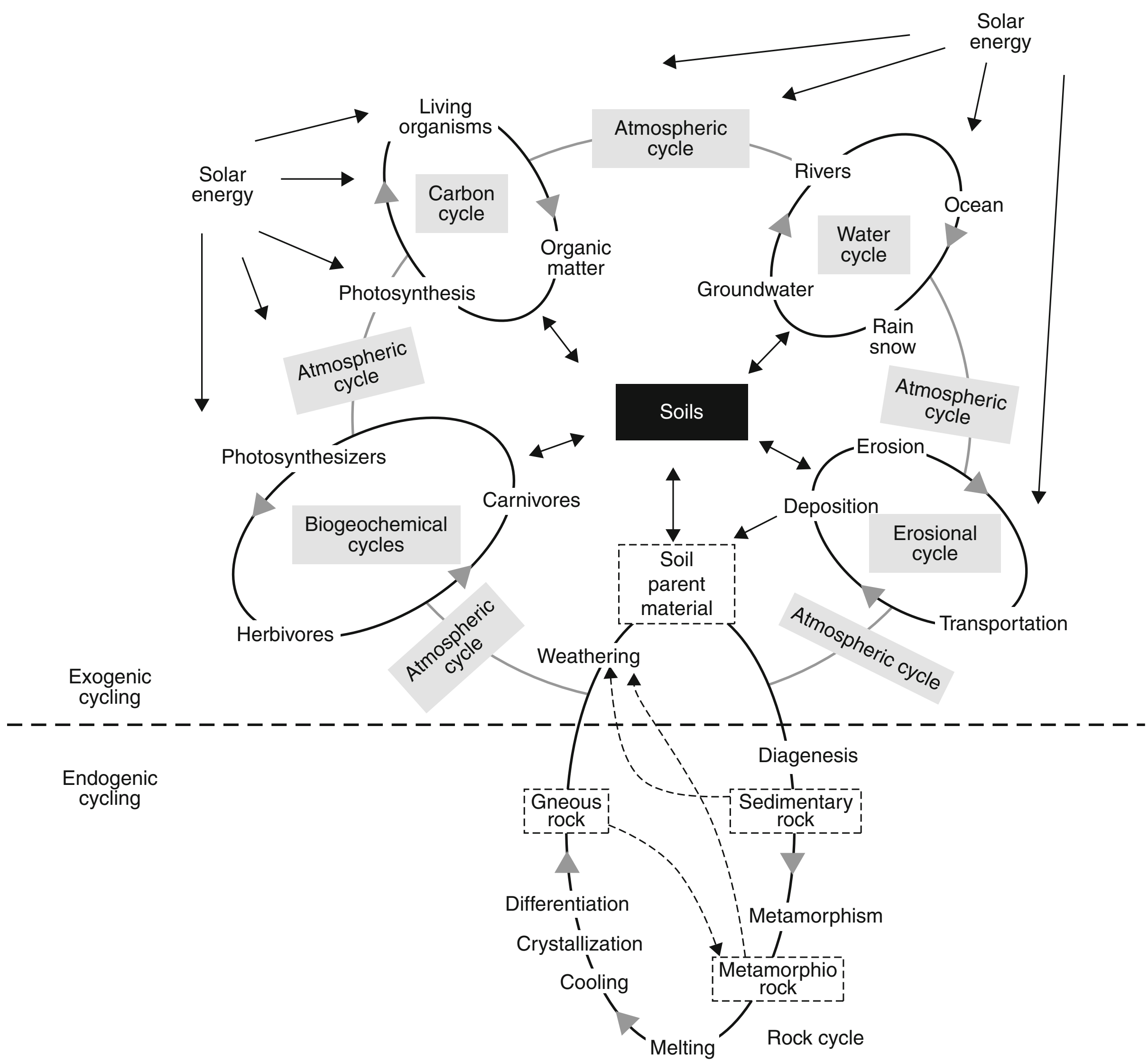
Definition

Agrogeology: any and all aspects of earth science that relate to agriculture and are impacted by agriculture.
Anthrobleme: the physical manifestation of human activities on the surface of the earth. From Greek roots meaning "human scar."
Anthropocene: the present geological age, taken to date from the Neolithic Revolution, approximately 10,000 years ago.

Biosphere: the surface and near-surface region of the earth where living organisms exist.
Deposition: the laying down or precipitation of materials at the surface of the earth.
Erosion: the loosening and removal of a rock or soil formation by natural or anthropic agencies.
Malthusian collapse: the state reached when population increases to outrun food resources. Named for the Reverend Thomas Malthus who published An Essay on the Principle of Population in 1798.
Neolithic Revolution: the transformation in human lifestyle that began slightly more than 10,000 years ago, when hunting and gathering began to give way to agriculture as the principal means of food production.
Transport: the movement of the products of weathering and erosion by water, wind, ice or biological (including human) activity.
Weathering: the chemical and physical breakdown of rocks and minerals at the surface of the earth.
Würm: the last ice sheet in Europe, between 24,000 and 10,000 years before the present. Roughly equivalent to the Wisconsinian glaciation in North America. Other local equivalents exist.

Introduction

Agrogeology is concerned with the science of geology in the context of agricultural science. The most obvious



Agrogeology, Figure 1 The centrality of soil in the exogenic, or external geological cycle on the earth, and its relationship with the endogenic, or internal cycle.

connection between the disciplines is soil, the geological substrate for the farmers' crop. But agriculture is massively contingent on geology for other reasons as well. Not only do the common geological processes of the planetary surface – weathering, transport and deposition – form soil in the first place, they are also implicated in the demise of soil, especially by the process of erosion (Chesworth, 2008).

Soil: the primary geological resource of the farmer

The centrality of soil on the earth's land surface is shown in Figure 1. It is an integral component of all major chemical and physical cycles of a geological nature, that take place there. Figure 2 depicts similar relationships, but with an important change of perspective. Seeing soil metaphorically in the neck of an hourglass, emphasizes its strategic position in the biosphere, but, importantly in the present context, emphasizes the vulnerability of the biosphere to any damage to the soil from natural or anthropic activities.

The evolution of soil can be thought of in terms of two geochemical pumps – a proton pump, and an electron pump. Protons are provided by two sources, rainwater (charged with CO_2) and the dissociation of –COOH groups on the breakdown products of organic matter. The dominant form of electrons in soil is decaying organic matter.

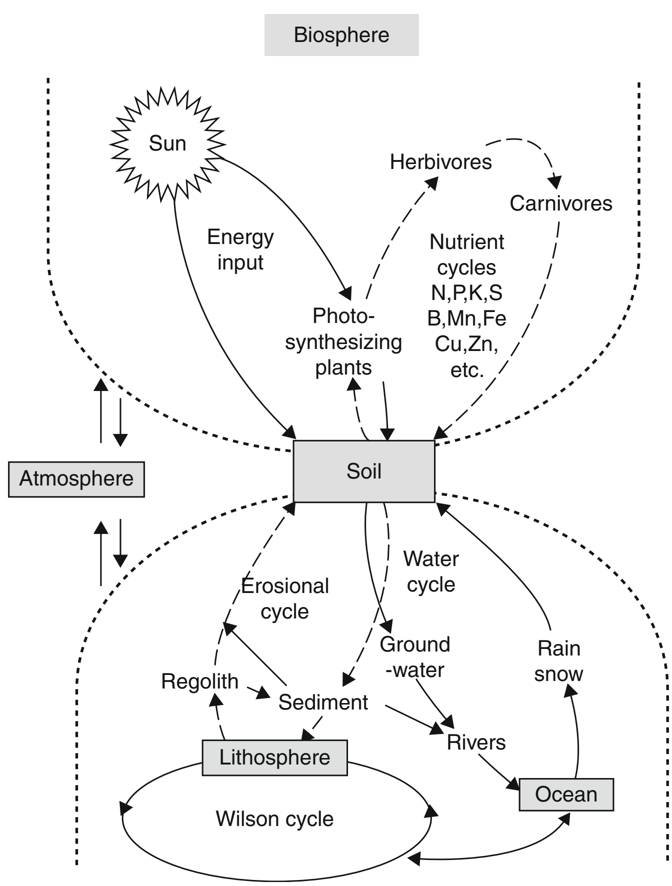
Protons flow from their source to a sink represented by the earth's surface, which acts as a base. A massive titration takes place during weathering, and in humid climates it amounts to an over-titration resulting in a progressive acidification of the soils of the land surface. In arid climates it is an under-titration, and soils progress along a path of alkalinization.

The dominant sink for electrons at the earth's surface, including within the pore space of unsaturated soils, is atmospheric oxygen. When this is unavailable, several ions in high oxidation states, may serve this function, e.g., nitrate, ferric Fe, manganic Mn, and others.

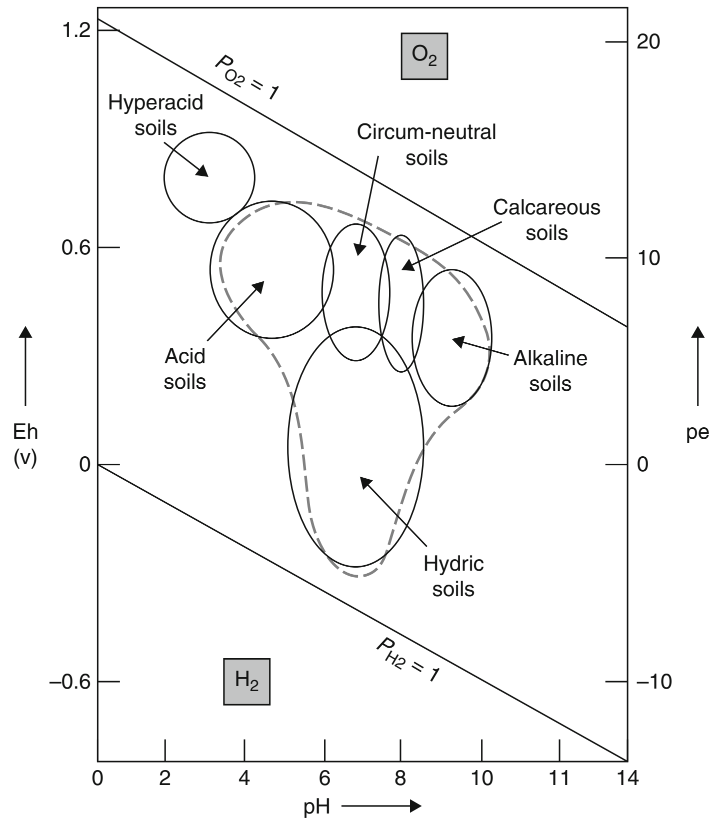
As a result of protons and electrons flowing from source to sink, the geochemical field of soil evolution covers an area of pe–pH space shown in Figure 3.

The geological scar of agriculture

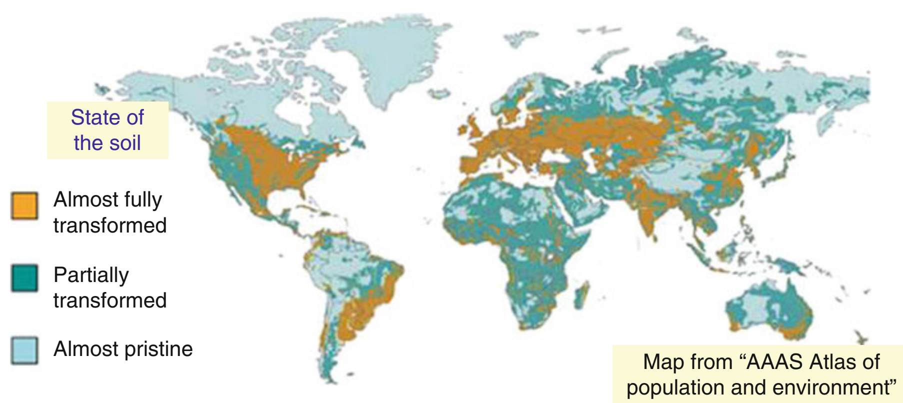
Anthropic effects on soil were relatively minor and local while the genus *Homo* was exclusively hunting and gathering, though when *Homo erectus* learned to control fire



Agrogeology, Figure 2 The hourglass paradigm, showing the critical vulnerability of the biosphere to changes in the soil covering the terrestrial landscape.



Agrogeology, Figure 3 A graphical representation of soils in terms of electron (pe) and proton (pH) variables. Hyperacid soils require a higher concentration of protons than those mentioned in the text, namely by the weathering of sulfides.



Agrogeology, Figure 4 Geological determinism in the pattern of human settlement (the anthrobleme, or human scar).

(perhaps as early as 1.8 million years ago), a powerful tool for clearing land became available. It may have been used as such by the hunters and gatherers in order to control the ease with which prey animals were hunted, but with the Neolithic invention of agriculture by *Homo sapiens*, some 10,000–12,000 years ago, it became the principal means by which land was deforested and made ready for cultivation. According to Ruddiman (2010), the agricultural deforestations that began then, marked the start of a buildup of greenhouse gases in the atmosphere, that received a further boost (as methane) when paddy-rice cultivation became dominant in east Asia about 5,000 years ago. The current threat of global warming may have a long agricultural pedigree.

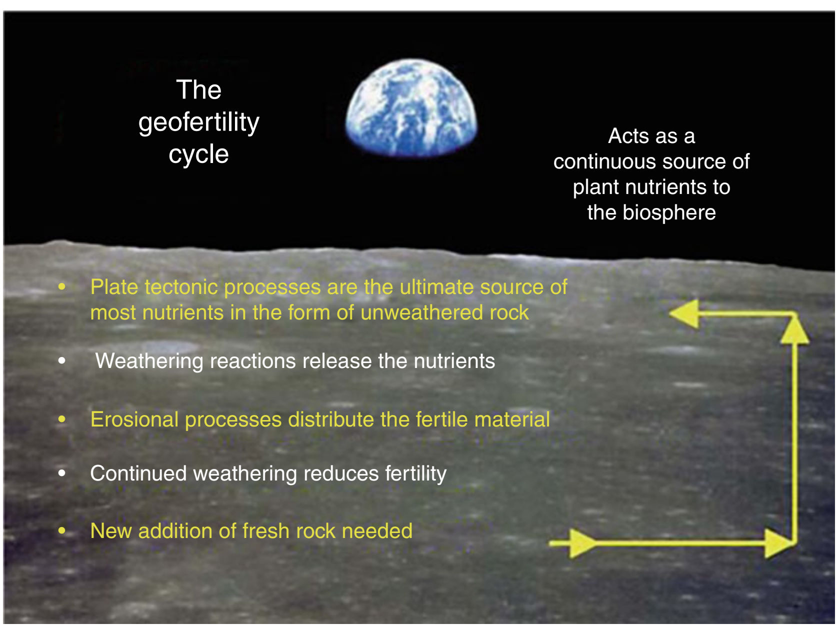
The earliest agriculturalists for which we have reliable archeological records, practiced their art in the crescent of highland that stretches from the Taurus mountains of southern Turkey to the Zagros mountains of Iran. Çatalhöyük in Turkey is particularly well investigated. Here, farmers depended on the soils developed on geological deposits laid down principally as alluvial fans. They chose light, silty soils that were easy to work, and that were moist for much, if not all of the year. They required no great advancements of technology – no ploughs, no irrigation canals – and they were in a region where the wild progenitors of their crops and farm animals were to be found. Large-scale developments became possible when the farmers, or their technologies migrated into the great river valleys enclosed by the highland rim. The Tigris and Euphrates provided a good source of water and of fertilizing sediments, and the effect was eventually extended onto arid soils when irrigation began to be practiced. It has been surmised that the need to manage water communally was an important impulse in the development of the first civilizations – Sumer, at the head of the Persian Gulf being the earliest on record.

Agriculture spread from its Middle Eastern birthplace to the Nile and the Indus, and because of their dependence on great rivers, the civilizations that developed are commonly referred to as hydraulic civilizations. The advent of agriculture in eastern Asia was probably independent, though it too was based on a large river system, the Huang Ho. In the Americas, farming developed independently of the Old World, and had a geological basis more similar to the agriculture of the Turkish highlands in being based on damp soils on the edges of lakes and wetlands, rather than the soils of large river valleys.

When agriculture expanded into Europe, it took two principal routes and each was facilitated by specific geological circumstances (Chesworth, 2010). The quicker route to the Atlantic was along the Mediterranean, with isolated communities probably developing at the mouths of coastal rivers where wet, light soils could be found. The original sites are probably lost now as a consequence of sea rise as the Würm ice sheet continued to retract. But isotopic dating confirms that the Mediterranean Coast of Iberia was reached some 7,500 years ago, and the Atlantic coast about a thousand years later. The slower route moved up to the Danube valley and used the light, fertile deposits of loess to cross central Europe to the west. In fact, the footprint stamped on the planet by *H. sapiens*, contains a large component produced by agriculture following the pattern of this important geological sediment, formed by the wind erosion of deposits left by receding ice (Figure 4). Agriculture reached the Atlantic coast of Ireland about 5,000 years ago.

Anthropocene

The early farmers depended in large part on the inherent fertility of the soils they were cultivating. This in turn depends upon the geo-fertility cycle (Figure 5). Fallowing was the simplest technology that allowed a cropped soil to recover fertility (by the weathering of minerals initially provided by the geo-fertility cycle). In essence, this early agriculture depended entirely on renewable resources – sunlight, water, a soil with a good inherent fertility, human muscle. In Egypt, with the Nile as a reliable delivery



Agrogeology, Figure 5 The geo-fertility cycle, the natural means whereby the inherent fertility of the soils of the biosphere is maintained. One major nutrient is not provided by this cycle, nitrogen. That requires the activity of nitrogen-fixing plants in the standing biomass.

system of both water and fertility, agriculture reached as close to a sustainable state as it is likely to get.

Since its Neolithic beginnings, has followed a path from the digging stick, to the ard, the wooden plough, and metal ploughs of increasing power, evolving in tandem with an increasing energy intensiveness, from human to animal muscle, and now to fossil fuel. Over the last 10,000 years or so, we have become the only organism to qualify as a geological force in our own right, a new phenomenon in the geological history of the planet, and one that justifies the recognition of the post Neolithic as a new geological period: the Anthropocene (Crutzen, 2000).

Conclusion

Currently, modern agriculture is utterly dependent on fossil fuels as well as on other nonrenewable geological resources. The rapidly depleting global reserve of natural gas, allows the artificial fixation of nitrogen, a service originally provided in the biosphere by N-fixing organisms. Other nutrient elements are made available by extraction from geological raw materials (phosphorites and potassium-bearing evaporates for example) on an industrial scale. The farming enterprise is now as far from sustainability as it has ever been, and with a world population of almost 7 billion people, a Malthusian collapse of human civilization in its present form, becomes ever more probable.

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Cross-references

Agrophysical Objects (Soils, Plants, Agricultural Products, and Foods)
Alkalinity, Physical Effects on Soils
Biochemical Responses to Soil Management Practices
Clay Minerals and Organo-Mineral Associates
Compaction of Soil
Cracking in Soils
Cropping Systems, Effects on Soil Physical Properties
Desertification: Indicators and Thresholds
Fertilizers (Mineral, Organic), Effect on Soil Physical Properties
Liming, Effects on Soil Properties
Management Effects on Soil Properties and Functions
Mechanical Resilience of Degraded Soils
Parent Material and Soil Physical Properties
Physical Degradation of Soils, Risks and Threats
Rheology in Soils
Salinity, Physical Effects on Soils
Soil Aggregates, Structure, and Stability
Subsoil Compaction
Soil Structure, Intersecting Surface Approach, and its Applications
Tillage Erosion
Tillage, Impacts on Soil and Environment
Water Erosion: Environmental and Economical Hazard
Wind Erosion

AGROPHYSICAL OBJECTS (SOILS, PLANTS, AGRICULTURAL PRODUCTS, AND FOODS)

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Definition

Agrophysical objects are those materials that play an important role in agricultural production. They are characterized by specific physical properties and undergo various natural and human-induced processes.

Four groups of main agrophysical objects are distinguished: soils, agricultural plants, agricultural products, and foods of plant origin.

Soils represent the greatest group among agrophysical objects. For agricultural crops, they are a medium, which is capable of physically supporting plants and constitutes a magazine for the water and nutrients essential for plant growth (Hillel, 2007; Chesworth, 2008). Soils are formed from the uppermost layer of earth crust (mother rocks) under the influence of five main factors: mother rocks, climate, vegetation, relief, and time. The properties of the soils are, in general, dependent on the above factors and therefore create a mosaic of taxonomic soil units as well over small as large areas, which are combined in very different qualities, quantities, and patterns. Soils are extraordinarily complex media, made up of a heterogeneous mixture of solid, liquid, and gaseous phases, as well as a diverse community of living organisms forming irregularities in their physical structure. They are comprised of different soil horizons (layers), aggregates, cracks, and texture classes. The mass of soil is nonrenewable. Even within the same volume of soil a great heterogeneity and anisotropy can be observed. Most soils are predominantly built of mineral material, but they have upper horizons of organic materials and there is a group of typically organic soils. In the near ground area, *microclimate* of cultivated field is distinguished (Physics of Near Ground Atmosphere).

From about 300 *agricultural plant* species 14 represent the major crops as a source of foods: wheat (the highest area in the world production), rice, maize, potatoes, barley, cassava, sweet potatoes, soya, beans, tomatoes, sorghum, leguminous grains, oats, millet, and rye (the lowest area in the world production) (Langer and Fill, 1991). Plant structure differs with growing conditions of plants and their individual organs (roots, stems, foliage, and harvestable products). As regards masses of plants, they may be bulk- or stored crops, or chopped or even pressed materials. Some plants, for example, willow, fiber crops, medicinal plants in the form of dead state, are used as agro-resources for the renewable energy, textile industry, building, and medicine.

Agricultural products are living or dead objects. Within their structure, particles, pores, and cells are distinguished. They have typical macroscopic dimensions and shapes. According to their mechanical properties they are divided into four classes: fluids, semiliquids, semisolids, and solids (Blahovec, 2008). Physical conditions during storage and processing of agricultural products such as temperature, moisture, aeration, and pressure affect their structure and quality.

Plant foods include plant and plant parts eaten as food without or after their processing. There are grain-based foods (cereals, legumes, and nuts), oils from oilseeds, fruits, vegetables, bread, and food extrudate products (Guy, 2001).

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AGROPHYSICAL PROPERTIES AND PROCESSES

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Definitions

Physical process is defined as: "A continuous action or series of changes which alters the material form of matter" and *physical property* as: "Any aspect of an object or substance that can be measured or perceived without changing its identity."

The term *Agrophysical processes and properties* concerns these processes and properties which are used in agrophysics and are relevant to agrophysical objects, i.e., soils, plants, agricultural products, and foods with particular reference to agricultural and environmental applications. Main agrophysical processes and related properties and their technological functions are: aeration, surface phenomena, electricity, mechanics, heat, and hydrology. Some of them are related to all objects or part of them and they have physical quantities expressed in SI units (Scott, 2000; Blahovec, 2008) (see also *Physical Dimensions and Units Use in Agriculture*). Soils which are the most important element of the natural environment undergo changes in their physical properties during natural soil development and also anthropogenic processes such as plowing, compaction, sealing and crusting, erosion, amelioration, loss of humus, salinization, reclamation, and contamination by inorganic and organic compounds (Blum, 2002; Horn and Baumgartl, 2002). Soil physical processes and properties and resulting soil functions have been specified by Lal and Shukla (2004). Physical processes and related properties of living plants in the field are subjected to environmental pressure, mainly weather conditions (Monteith and Unsworth, 2007) and agricultural products are subjected to technology of food processing (Mohsenin, 1986).

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Cross-references

Agrophysics: Physics Applied to Agriculture
Air Flux (Resistance) in Plants and Agricultural Products
Bending Properties of Plants
Biocolloids: Transport and Retention in Soils
Bypass Flow in Soil
Coupled Heat and Water Transfer in Soil
Flocculation and Dispersion Phenomena in Soils
Infiltration in Soils
Organic Matter, Effects on Soil Physical Properties and Processes
Pedotransfer Functions
Physical Dimensions and Units Use in Agriculture
Plant Lodging, Effects, and Control
Pore Size Distribution
Shrinkage and Swelling Phenomena in Agricultural Products
Shrinkage and Swelling Phenomena in Soils
Solute Transport in Soils
Water Erosion: Environmental and Economical Hazard

AGROPHYSICS: PHYSICS APPLIED TO AGRICULTURE

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Definition

Agrophysics is a science that studies physical processes and properties affecting plant production. The fundaments of agrophysical investigations are mass (water, air, nutrients) and energy (light, heat) transport in the soil–plant–atmosphere and soil–plant–machine–agricultural products–foods continuums and way of their regulation to reach biomass of high quantity and quality with the sustainability to the environment. The knowledge of physical phenomena in agricultural environment allows increasing efficiency of use of water and chemicals in agriculture and decreasing biomass losses during harvest, transport, storage, and processing.

Short history

The term *agrophysics* was proposed by the Russian physicist A.F. Ioffe (1880–1960) to cover the relations within the soil environment, and especially those of the mass and energy transfer in the soil–plant–atmosphere system (The Agrophysical Institute of the Russian Academy of Agricultural Sciences in Saint-Petersburg: The Roots of Agrophysics). Agrophysics was defined as "a science that studies physical, physicochemical, and biophysical processes in the system 'the soil – the plants – the active layer of the atmosphere' as well as main principles of the production process, physical properties of the system components and of various agricultural products." Over time, it expanded onto other materials, such as agricultural crops, agricultural raw materials and foods, and soil–machine and machine–plant relations. Penman (1948) called attention to the role of physics in agriculture, and later on Przestalski (2001) explicitly argued that "Many phenomena important for agriculture (e.g., soil structure and interactions that determine it, water transport in the soil, transport of water and mineral nutrients in the soil–plant system, effects of the temperature, radiation and other factors on the crop yields, substance permeation through the membranes, and others) which are subjected to physics laws can be investigated with the physical methods only."

Agrophysics was further developed by Polish scientists B. Dobrzański, J. Gliński, J. Haman, B. Szot, R. Walczak and East European institutions, such as: Institute of Agrophysics of the Polish Academy of Sciences and European Union Centre of Excellence in Lublin "Agrophysics," Poland (Institute of Agrophysics in Lublin: Progress in Agrophysics); Agrophysical Institute of the Russian Academy of Agricultural Sciences in Saint-Petersburg (Russia); Czech University of Agriculture in Prague (Czech Republic); Hydrological Institute of the Slovak Academy of Sciences in Bratislava (Slovakia); Agricultural University in Gödöllo (Hungary); Research Institute of Soil Science and Agricultural Chemistry of the Hungarian Academy of Sciences in Budapest (Hungary); N. Pushkarov Institute of Soil Science, Sofia (Bulgaria); Centre of Agricultural Landscape and Land Use Research, Müncheberg (Germany); Institute for Problems of Natural Resources Use and Ecology BAS, Minsk (Belarus); Research Institute for Soil Science and Agrochemistry, Bucharest (Romania); Institute for Soil Science and Agrochemistry Research, UAN, Kharkiv (Ukraine); and Institute of Physicochemical and Biological Problems of Soil Science and Institute of Basic Biological Problems RAS, Puschino (Russia). This cannot be forgotten about other institutions contributing in the progress of agrophysics, collaborating for many years with the Institute of Agrophysics in Lublin. They are: University of Agricultural Sciences, Institute of Soil Science, Vienna (Austria); Ghent University, Department of Soil Management and Soil Care, Gent (Belgium); University of Guelph, Ontario Agricultural College, Department of Land Resources Sciences (Canada); Institute of Soil Science, Academia Sinica, Nanjing (China); Cranfield University, Silsoe College, Land Resources Division, Silsoe (England); University of Helsinki, Agricultural Chemistry and Physics, and Agrifood Research Centre of Finland, Jokioinen (Finland); Institute of Soil Science, Montfavet (France), Christian Albert University, Institute of Soil Science and Plant Nutrition, Kiel; University Hohenheim, Institute of Soil Science, Stuttgart; Technical University Berlin, Institute Ecology, Department of Soil Science and Soil Protection, Berlin (Germany); Winand Staring Center for Integrated Land, Soil and Water Research SC-DLO, Wageningen (Holland); Institute of Mechanisation of Agriculture CNR, Torino (Italy); Hokkaido University, Laboratory of Soil Science, Sapporo, and Graduate School of Bioagricultural Science, Nagoya (Japan); Institute of Natural Resources and Agrobiology IRNAS-CSIC, Sevilla (Spain); Sweden University of Agricultural Sciences, Department of Soil Science, Uppsala (Sweden); University of Kentucky, Department of Agricultural Engineering, Lexington; and Coastal Plains and Soil Water Conservation Research Center, Florence, South Carolina (USA).

Scientific symposia, conferences, and meetings presented various aspects of agrophysics. The most progressive were the international conferences organized in: Lublin, Poland (1976, 1997) (Figure 1); Gödöllo, Hungary (1980); Prague, Czechoslovakia (1985); Rostock, East Germany (1989); Bonn, West Germany (1993); Brussels, Belgium (2004); Lublin, Poland (2005). Also many bilateral conferences: Polish–Czechoslovak on "Physics of soil water," Polish–Hungarian on "Mechanical properties of agricultural materials" and on "Soil degradation," Polish–French on "Agricultural and hydrological aspects of soil amelioration" were organized since 1973. Most presentations from these conferences were published in various journals, including the International Agrophysics, e.g., Special issue, 1994. Vol. 8, Nos. 1–4.

In Poland, very active is the Polish Society of Agrophysics (Polish Society of Agrophysics) and an important role in the promotion of agrophysics is played by the journals *International Agrophysics* and *Acta Agrophysica.*

Since 2001, every spring international workshops for young scientists, *BioPhys Spring,* are systematically organized, alternately by the Czech University of Agriculture

Agrophysics: Physics Applied to Agriculture, Figure 1 Participants of the 6th International Conference on Agrophysics, (6 ICA), September 15–18, 1997, Lublin, Poland.

in Prague and the Institute of Agrophysics in Lublin. The meetings are oriented on training of young researches and on exchange of professional experience in physics applied to biological, agricultural, and food systems. In 2008, the Slovak University of Agriculture in Nitra and the Szent Istvan University in Gödöllo (Hungary) joined the Organizing Committee of the Workshops, increasing the international level of the event.

Books (Gliński and Stępniewski, 1985; Gliński and Lipiec, 1990; Przestalski, 2009) and a set of monographs on various problems of agrophysics were published within the scope of activity of the Institute of Agrophysics in Lublin and the EU Centre of Excellence "Agrophysics": Baranowski and Walczak (2004); Bieganowski and Walczak (2004); Bieganowski et al. (2004); Józefaciuk (2004); Józefaciuk et al. (2004); Gliński et al. (2004); Lipiec et al. (2004); Matyka-Sarzyńska and Walczak (2004); Skierucha and Walczak (2004); Skierucha and Malicki (2004); Skierucha et al. (2004); Sławiński et al. (2004); Stępniewski et al. (2005); Usowicz and Usowicz (2004); Witkowska-Walczak et al. (2004); Baranowski et al. (2005); Horabik and Laskowski (2005a, b); Konstankiewicz and Zdunek (2005); Raytchev et al. (2005a, b); Szot et al. (2005); Włodarczyk and Kotowska (2005); Dobrzanski et al. (2006); and Szymanek et al. (2006). To facilitate access to the worldwide literature on agrophysics, a six-language (English, German, Spanish, French, Polish, and Russian) dictionary on agrophysics, containing 2,800 terms, was elaborated (Dębicki et al., 1991).

Agrophysics is related to the *agrosphere* which is one of the Earth spheres. The Agrosphere Institute ICG-4 of the Forschungszentrum Jülich, Germany, indicates a role of a network of scales and disciplines in the agrosphere. They start with molecule scale to soil column, pedon, field, regional, and superregional scales using NMR, NMR imaging, resistance tomography, and remote sensing methods depending on the scale (http://www.fz-juelich.de/icg/icg-4/).

Importance of agrophysical research

Agrophysics is developing dynamically, linking knowledge in environmental physics, plant physics, and food physics, filling the gap between such disciplines as agrochemistry, agrobiology, agroecology, and agroclimatology. Agrophysical knowledge is useful in agricultural research and practice, especially in agronomy, agricultural engineering, horticulture, food and nutrition technology, and environmental management (Frączek and Ślipek, 2009). Application of agrophysical research allows reduction of losses of agricultural products at harvest and post harvest processes and storage.

Progress in agrophysics was possible due to the joined activity of agronomists, physicists, chemists, and biologists, resulting in interdisciplinary approach and solution of theoretical and instrumental problems focused on their practical application in agriculture and natural environment. Agriculture contribution to greenhouse gases production and sink in soils and emission to the atmosphere is closely connected with soil physical properties (Włodarczyk and Kotowska, 2005).

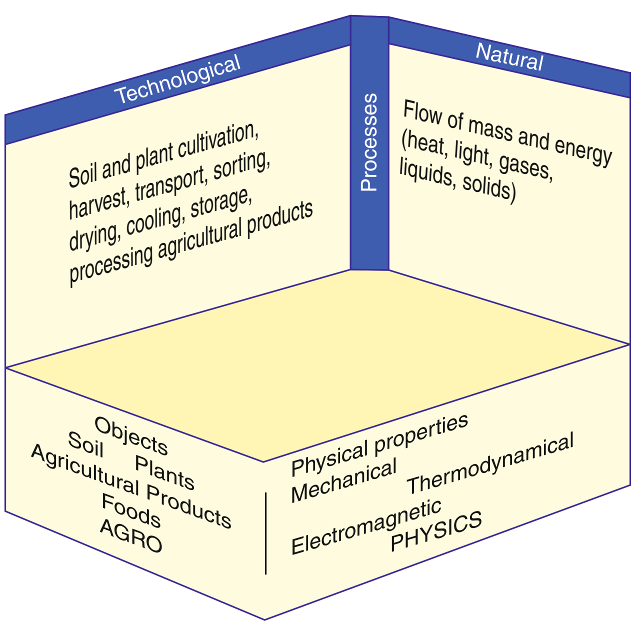
Application of physical methods, laws, and theories for the agricultural problems allowed for more precise description and modeling of the above processes (Haman, 2003).

The area of agrophysical activity may be presented on a three-axial configuration (Figure 2), and the basic scheme of agrophysical research is shown in Figure 3.

Agrophysical knowledge plays an important role in appropriate *processing and storing* of agricultural products and foods which use modern technologies and physical laws that control behavior of biological materials. Agriculture and the food industry belong to largest producers and users of granular materials. Increasing number of processes and operations involving granular materials have resulted in a growing need for new theory and technology. Elaboration of effective design methods of technological processes requires detailed knowledge of physical properties of the processed material as well as proper understanding of interactions with construction materials, e.g., silos (Ravenet, 1981).

Agrophysical objects

The main objects of agrophysical investigations are soils, plants, and agricultural products and foods (see *Agrophysical Objects (Soils, Plants, Agricultural Products, and Foods)*). From the physical point of view, the three states of matter (solid, liquid, gas) can occur in every agrophysical object.

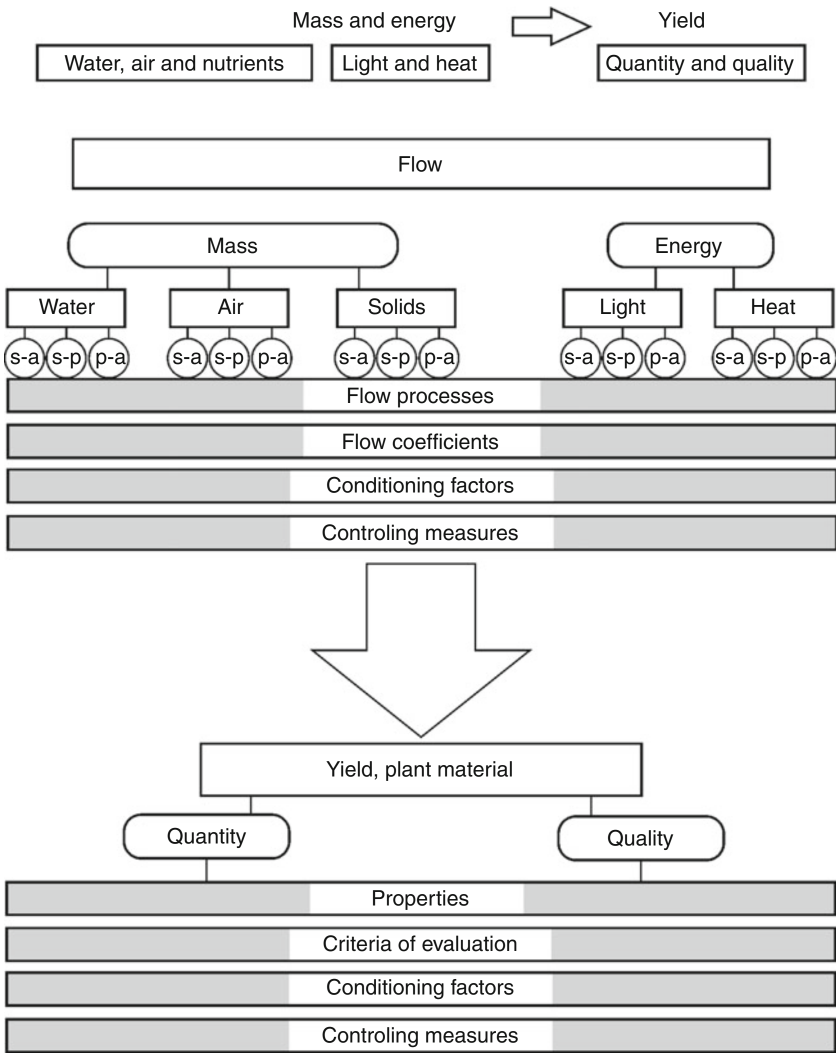


Agrophysics: Physics Applied to Agriculture, Figure 2 Three-dimensional scheme of agrophysical research (Adapted from Gliński, 1992).

Soils

Soils are the central link in the terrestrial environment (Hillel, 2007; Chesworth, 2008) due to their ecological functions (Soil Functions). The functions are largely influenced by soil physical characteristic parameters (see *Agrophysical Properties and Processes*) which are well described in many books by e.g., Hillel (1972, 1982, 1998, 2004, 2007); Hanks and Askroft (1980); Gliński and Stępniewski (1985); Gliński and Lipiec (1990); Hartge and Horn (1991); Marshal et al. (1996); Koorevaar et al. (1999); Scott (2000); Shein and Goncharov (2000); Smithson et al. (2002); Warrick (2002); William and Horton (2004); Lal and Shukla (2004). It is enough to mention water, air, and thermal, mechanical, and rheological properties which determine the conditions for crop production, assuming at the same time efficient use of chemicals and agricultural machines. In the evaluation of soil properties and processes, scale (length and time) problems (Scaling of Soil Physical Properties) are considered. For water transport in the porous system of soil Kutilek and Nielsen (1994) proposed four length scales, from submicroscopic (10^{-10} to 10^{-8} m) through microscopic (10^{-6} to 10^{-3} m), macroscopic (10^{-1} to 10 m) to watershed (10^{2} to 10^{4} m and even more). The response time for changes in these parameters is in a broad scale. The changeability of other soil physical characteristics are, e.g., $<10^{-1}$ year for bulk density, total porosity, and composition of soil air, 10^{0}–10^{-1} year for cation exchange capacity, 10^{-1}–10^{2} year for clay mineral associations, $>10^{3}$ year for texture (Arnold et al., 1990).

Nowadays, worldwide problems closely connected with soil physical properties are soil erosion and compaction. Water and wind erosion are disastrous phenomena in many places. Soil erosion causes tremendous damage, e.g., in America, which loses at the level of 4.8 billion tons of topsoil of agricultural land annually due to erosion (Arnold et al., 1990, p. 78). In Africa, these losses are equal to 700 Mg km^{-2} and in Europe 84 Mg km^{-2}. Closely related with soil erosion are such phenomena as surface soil sealing and crusting, and destruction of soil structure (see *Water Erosion: Environmental and Economical Hazard*; *Soil Surface Sealing and Crusting*). Soil compaction is a severe problem now due to increasingly using heavier tractors, larger implements, bigger combines, reduced tillage, and no-tillage systems (Horn et al., 2000). Conducting field operations when the soil is too wet, especially in spring and harvesting in the fall increase compaction. Compaction increases soil bulk density and mechanical impedance to root growth and reduces soil macro-porosity, affecting water and air conditions both for plant growth and yield. Nearly all great agroecological programs directed at increasing soil productivity or soil protection against degradation or land conservation include investigations on the physical processes and properties in soils (see *Soil Aggregates, Structure, and Stability*; *Soil Compactibility and Compressibility*; *Soil Erosion Modeling*; *Soil Surface Sealing and Crusting*).



Agrophysics: Physics Applied to Agriculture, Figure 3 Basic scheme of agrophysical research. *a* atmosphere, *p* plants, *s* soil (Adapted from Gliński, 1992).

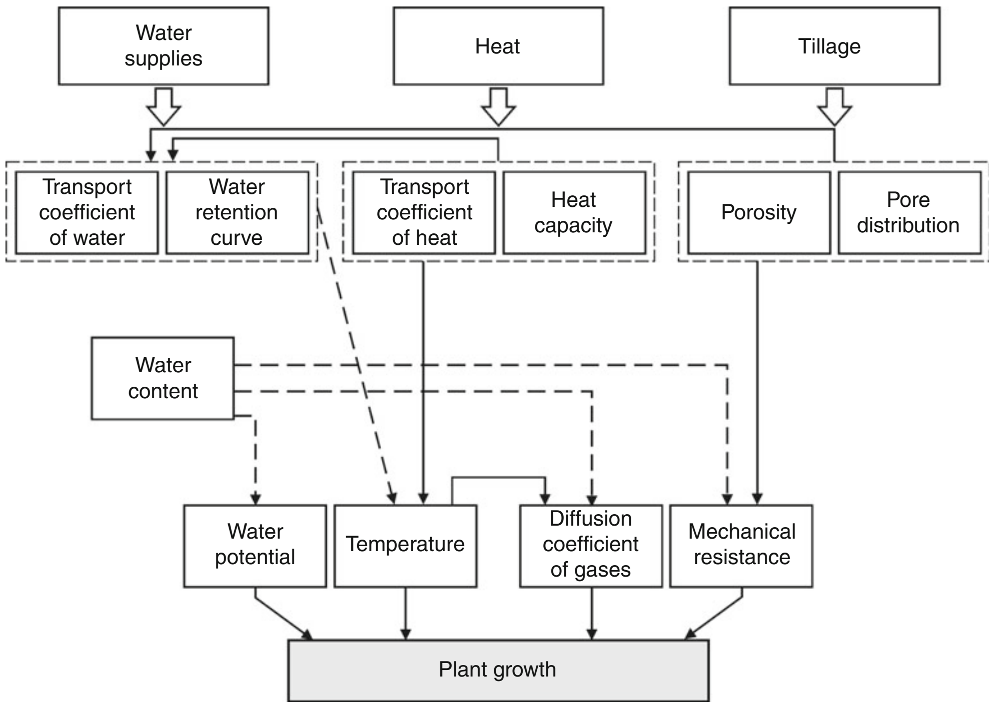
Additionally, the variability and large heterogeneity of soil properties gives the view of difficulties to be faced by the physicist dealing with measurements performed in the soil environment (Bieganowski and Walczak, 2004). For this reason, there are still problems concerning standardization of physical methods used in agrophysics (ISO) (see *Standardization in Agrophysics*).

It is worth to mention here the near-ground atmosphere which forms the *microclimate* (Physics of Near Ground Atmosphere) of a cultivated field with plant canopy, where the processes of evapotranspiration play an important role (Monteith and Unsworth, 2007).

Plants

Productivity of agricultural plants is highly affected by physical factors that are determined by soil tillage, land management, and climate (Szot, 1976; Gliński and Stępniewski, 1985; Letey, 1989; Gliński and Lipiec, 1990; Lipiec et al., 2004; Gliński et al., 2008) (Figure 4).

Plants differ within themselves and within their organs such as: the root system, stem, foliage, fruit, not to mention the complex structure of each component. Further sharp distinction has to be made as regards the post harvest mass of plants which may be in bulk, stored crops, chopped or even pressed material. The knowledge on the physical properties of plants is useful in plant breeding to improve resistance to lodging and crop productivity and quality (see *Plant Lodging, Effects, and Control*; *Plant Physical Characteristics in Breeding and Varietal Evaluation*). Moreover, plants are important source of biomass for renewable energy production in many countries (see *Alternative Sources of Energy from Agriculture Biomass – a European Perspective*; *Biomass as an Environmentally Benign Energy Source*).



Agrophysics: Physics Applied to Agriculture, Figure 4 Physical factors influencing plant growth (Adapted from Walczak and Zawadzki, 1979).

Agricultural products

Agricultural products are composed of living or harvestable products of plant origin. It is not easy to separate agricultural products from foods. Generally, they are raw materials for foods after their storage and processing, but some of them (vegetables, fruits) can be eaten as fresh foods. Many agricultural products are irregular in shape, with convex and concave parts on different surfaces and a characteristic internal structure consisted of particles, pores, and cells (Blahovec, 2008). The mechanical properties of agricultural products play an important role in the transport, storage, and processing of these materials. Fruit properties, such as porosity, surface area, mass, volume, dimensions, friction, and color are significant in sorting, storing, and packing. Agricultural raw materials, products, and foods must fulfill stringent requirements and standards, including their physical properties, which should be currently and quickly checked during their processing. Agricultural tools and machines used during harvest and transport cause yield losses and mechanical damage (see *Crop Yield Losses Reduction at Harvest, from Research to Adoption*). Physical processes during storage and drying of biological materials may cause their mechanical and biological damage and thus worsening quality. Application of physics provides bases for new technologies on maximal reduction of above-mentioned losses during various operations (Mohsenin, 1986).

Plant foods

Plant foods include plant and plant parts eaten as food without or after their processing (see *Agrophysical Objects (Soils, Plants, Agricultural Products, and Foods)*). The knowledge of physical properties affects their quality during post-harvest operations, storing, and processing (Heldman, 2003; Sahin and Sumnu, 2006). Quality of food is the multiparameter attribute related to sensory properties (appearance, texture, taste, and aroma), nutritive values, chemical constituents, mechanical properties, functional properties, and defects. An important physical element of food quality is texture. The texture is a sensory and functional manifestation of the structural, mechanical, and surface properties of foods detected through the senses of vision, hearing, touch, and kinesthetics (Szczesniak, 2002). Texture is affected by the structure of food (Jackman and Stanley, 1995). Texture of plant foods can be attributed mainly to the structural integrity of the cell wall and middle lamella, as well as to the turgor pressure generated within cells by osmosis. It is well known that texture of fruits and vegetables is influenced by cell wall structure (thickness, chemical composition), middle lamella, turgor pressure, parenchyma cells arrangement, quality and volume of intercellular spaces, permeability of cell walls.

Main agrophysical processes, properties, and their technological functions are presented in Table 1.

Agrophysics: Physics Applied to Agriculture, Table 1 Main agrophysical processes and properties and their impacts on soil, plants, agricultural products, and food

Physical processes	Physical properties	Impact on soil and plants	Impact on agricultural products and food
Mass transport (water, vapor, air, and chemicals flow; capillary flow, molecular diffusion, osmosis)	Hydraulic conductivity, water diffusivity, vapor diffusivity, air diffusivity, chemicals diffusivity, permeability	Water available to plants, seepage, filtration, drainage, irrigation, flooding, chemical transport, gas emission from soil, aeration, evaporation, respiration, transpiration, weathering, erosion, runoff, soil sealing, and crusting	Chilling, cooling, drying, and fumigation of products in bulk, storage respiration, shelf life
Mass absorption/adsorption (adhesion, cohesion)	Particle size distribution, porosity, surface area, wettability	Waste disposal, gas exchange, coagulation, flocculation, peptization, shrinkage	Drying, hydration, dehydration, storage respiration
Energy transport (heat conduction, convection, radiation)	Thermal conductivity, heat capacity, specific heat, permittivity	Thermal condition	Drying, processing, cooking
Energy absorption/emission (heat conduction, radiation)	Reflectance, absorption, permittivity, dispersion, color indices	Thermal condition, albedo, growing degree-days	Drying, heating, processing
Phase transition (evaporation, condensation, crystallization, melting)	Latent heat, melting heat	Soil freezing/thawing, plant freezing	Freezing, freeze-drying, storage
Mechanical processes (impact, compression, crushing, shearing, tension)	Elasticity, viscosity, plasticity, hardness, density, porosity	Soil tillage, soil aggregation, soil compaction, trafficability, plant lodging, emergence	Harvesting, post-harvest treatment, storage, handling, processing (agglomerating, chopping, mixing, separating)

Agromechanics

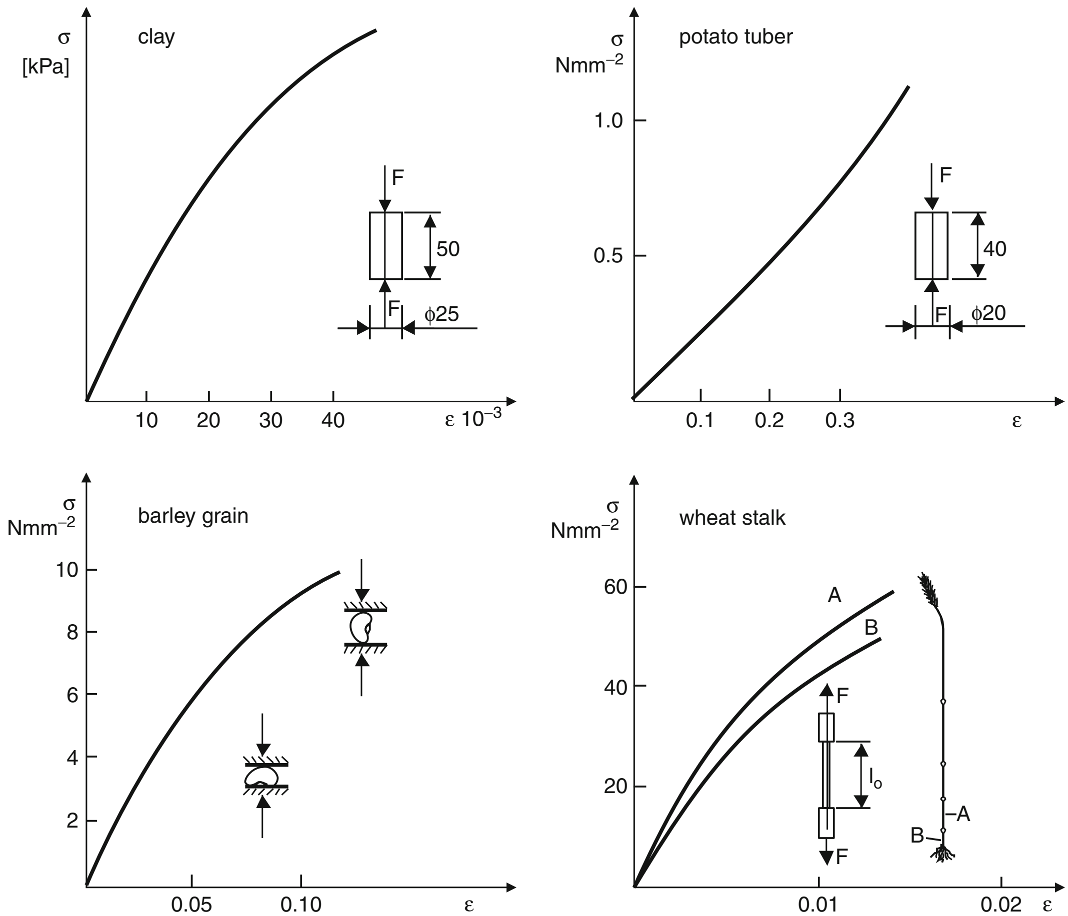
Agricultural objects undergo mechanical changes but their cognition is difficult because of the very complicated structure (Koolen and Kuipers, 1983; Husar, 1985; Haman, 1988). Therefore the application of results from engineering mechanics to agromechanics is difficult. The most important areas of agromechanics are related to the strength of agricultural products and to the determination of stresses and strains occurring in the system. Agrophysicists make effort to acquire knowledge on the effects of stresses acting on agricultural objects. In the case of agricultural products, external forces are coming from the effects of a body's own weight, wind force, supporting force, shock, vibration, mechanical interference. Internal forces appear, e.g., between stalk and nodes, stalk and root system in cereals, or tuber and foliage. Examples of stress–strain relations of some agrophysical objects are shown in Figure 5. The tasks connected with the transport and processing of agricultural products, such as baling, milling, grinding, etc., depend fundamentally on the machinery used. In the case of soils, the natural influences and human interventions that cause the stress–strain relations in soils are even more difficult to determine. Advances in applied physics with extended theoretical knowledge are needed to know mutual interactions of machine elements with plants.

In the conditions of intensive agriculture, problems of the level of *energy use* in various technological processes are of fundamental significance. Especially soil cultivation and yield harvest consume a lot of energy which can be decreased by applying knowledge of the physical properties of agrophysical objects and machines used.

Main tools in agrophysical research

Measuring methods, instrumentation, and metrology

Study of the multiphase and heterogeneous system of agricultural objects is very complex and therefore needs to adopt many measurement methods and instrumentations used in other scientific disciplines (Gliński and Konstankiewicz, 1991a, b; Walczak, 1993; Blahovec and Kutilek, 2003; Lamorski et al., 2004). The scientists need precise quantitative information concerning the physical behavior and spatial variability of examined objects to create models for practical use after their experimental verification. For this purpose, many advanced methods and measuring tools were recently developed. Some of them are considered in the Encyclopedia of Agrophysics (see *Acoustic Tomography*; *Electrochemical Measurements in Soils*; *Electrical Resistivity to Assess Soil Properties*; *Electromagnetic Fields, Impact on Seed Germination and Plant Growth*; *Fractal Analysis in Agrophysics*; *Ground-Penetrating Radar, Soil Exploration*; *Image Analysis in Agrophysics*; *Nanomaterials in Soil and Food Analysis*; *Neural Networks in Agrophysics*; *Nondestructive Measurements in Fruits*; *Nondestructive*



Agrophysics: Physics Applied to Agriculture, Figure 5 Stress–strain diagrams for clay, potato tuber, barley grain, and wheat stalk (Modified from Husar, 1985).

Measurements in Soil; *Nuclear Magnetic Resonance (NMR)*; *Particle Film Technology*; *Porosimetry*; *Precision Agriculture: Proximal Soil Sensing*; *Proximal Soil Sensing*; *Proton Nuclear Magnetic Resonance (NMR) Relaxometry in Soil Science*; *Remote Sensing of Soils and Plants Imagery*; *Tensiometry*; *Visible and Thermal Images for Fruit Detection*; and *X-ray Method to Evaluate Grain Quality*).

Modeling

In agrophysics, one of the basic methods of investigation is modeling. Modeling, like scientific observation and experimentation, is a method for increasing our understanding of cause-and-effect relationships. It requires classifying the processes involved according to their importance, which results in the creation of a simplified reality (see *Stomatal Conductance, Photosynthesis, and Transpiration, Modeling*).

Generally, the models used in physics and in other life sciences, including agrophysics, can be divided into physical and mathematical models. The physical models, with regard to the way of description of processes taking place in the environment, can be divided into: real models, analogue models, and phenomenological models (Mazurek et al., 1996).

The *real models* concern field or laboratory experiments (lysimetric and pot studies, greenhouse experiments). The *analogue models* enable the description of a given object, phenomenon, or physical process with the help of another analogous object, phenomenon, or physical process. The analogue models are created to simulate slow real process, e.g., the flow and accumulation of water in a porous medium can have an analogue in the flow and accumulation in a net of resistances and condensers. The *phenomenological models* are constructed when a real process is too complicated for a detailed physical–mathematical description (e.g., evapotranspiration, erosion, biomass production).

Recent development of computer technology and information management (or programming) enhances the importance of mathematical models. A mathematical model is an equation or set of equations whose solution describes the physical behavior of a related physical system. A mathematical model is always a simplified description, or caricature, of a physical reality expressed in mathematical terms (Weatherley, 2006).

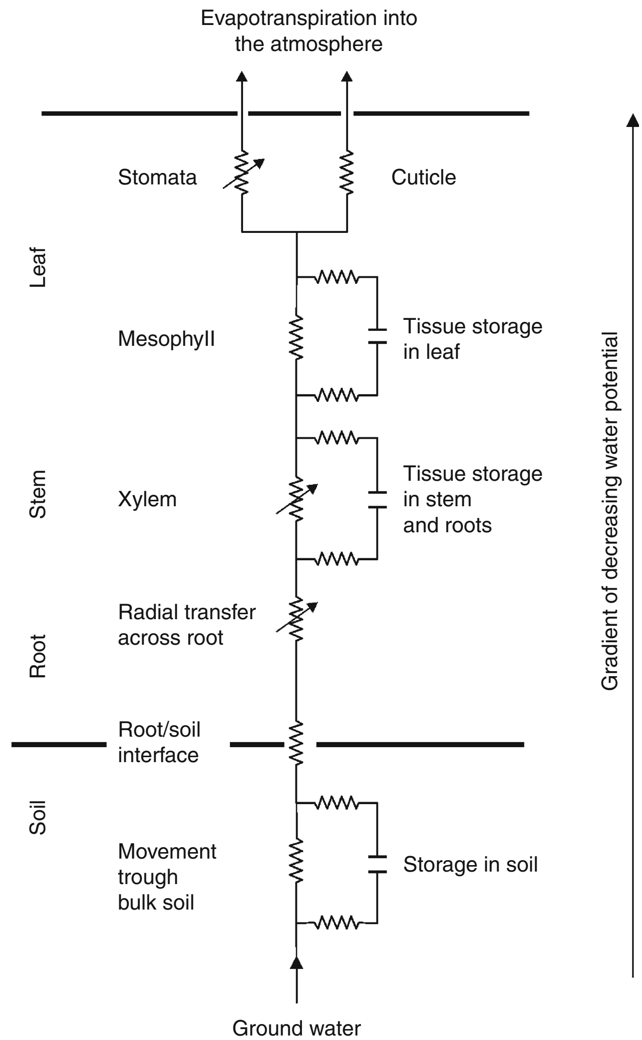
Mathematical models can be divided into mathematical–physical, statistical–physical, and mathematical–statistical models. They may be used for different applications – from pure modeling of transport phenomena in soil to crop growth and yield prediction.

A typical example of mathematical–physical model is the mass and energy transport through the soil–plant–atmosphere system (see *Soil–Plant–Atmosphere Continuum*) as a principal agrophysical phenomenon. It results from a combination of various mechanisms and includes molecular liquid diffusion, molecular vapor diffusion, capillary flow, convective transport, evaporation–condensation, pure hydrodynamic flow, and movement due to gravity. This transport can be described by 3D nonlinear differential equations with coefficients that can be determined experimentally. Water movement through the system was presented as a series of interrelated, independent processes which can be treated as analogous to the flow of electricity through a conducting system (Figure 6).

Complex mathematical–physical models are developed to describe soil, atmosphere, and plant processes responsible for biomass increase, using constitutional mathematical–physical equations (e.g., van Genuchten, 1980). The equations are resulting from the conservation laws, describing a chosen phenomenon in this system, e.g., transport of water, salt, and heat in the soil; soil deformation; and stress as a result of agricultural machines and cultivation tools reaction (Haman and Pukos, 1983; Pukos, 1994; Walczak et al., 1997; Konstankiewicz and Pytka, 2008).

Other examples of mathematical–physical models are models using the discrete element method (DEM) and finite element method (FEM) for modeling physical processes in various media (e.g., grain silos) (Holst et al., 1999a, b).

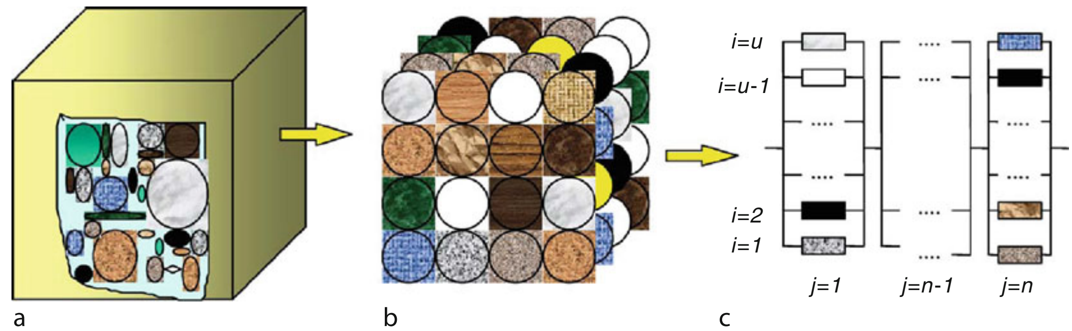
An example of a statistical–physical model is the model of soil thermal conductivity proposed by Usowicz et al. (2006). The model is expressed in terms of heat resistance (see *Ohm's law and Fourier's law*), two laws of Kirchhoff, and the polynomial distribution. The volumetric unit of soil in the model (Figure 7a) consists of solid particles, water, and air, and is treated as a system made up of regular geometric figures, spheres, filling the volumetric unit by layers (Figure 7b). It is assumed that connections between the layers of spheres and the layer between neighboring spheres will be represented by serial and parallel connections of thermal resistors, respectively (Figure 7c). Comparison of resultant resistance of the system, with consideration of all possible configurations of particle connections together with a mean thermal resistance of given unit soil volume, allows estimating the thermal conductivity of soil ($Wm^{-1}K^{-1}$).



Agrophysics: Physics Applied to Agriculture, Figure 6 Diagram of water flow from soil to the atmosphere through plants (Adopted from Russel, 1977).

An example of mathematical–statistical models are pedotransfer functions (PTF), being equations or algorithms expressing relationships between soil properties different in the difficulty of their measurement or their availability. PTFs are vital tools to translate data that we have to data that we need in agrophysical research and management applications (Pedotransfer Functions). They were extensively used to predict soil hydraulic properties (retention curve, hydraulic conductivity) from basic soil properties such as particle-size distribution, organic matter, and bulk density.

Global warming resulting in climate change and its possible effects on the soil environment and the economy yielded the creation of simulation models concerning also predicted changes of soil parameters. The model of soil water balance, being a combination of mathematical–physical and phenomenological models, was elaborated



Agrophysics: Physics Applied to Agriculture, Figure 7 Schematic diagram of structure of the statistical model where (**a**) is a unitary volume of soil, (**b**) is the system of spheres that forms n layers, and (**c**) is a representation of contacts in layers by u parallel connection of resistors (Usowicz et al., 2006).

for the territory of the European Community within the ACCESS project (Agro-climatic change and European soil suitability – a spatially distributed soil, agro-climatic and soil hydrological model) (Loveland, 1996). One of its submodels on bypass flow in cracking soils was done and experimentally verified (Armstrong et al., 1996; Sławiński et al., 1996; Walczak et al., 1996; Fernandez et al., 2004).

Mathematical modeling contributes to better understanding of the complex and variable effects of soil and subsoil compaction (Lipiec et al., 2003). Frequently, mechanistic and deterministic models were used. Root growth is often predicted as a function of mechanical resistance and water status of soil and crop yield from interactions of soil water and plant transpiration and assimilation. Modeling of the movement of water and chemicals is based on the Darcy/Richards one-dimensional flow equation. The effect of soil compaction is considered by changing hydraulic conductivity, water retention, aeration, and root growth. The predictability of some models was improved by considering macroporosity and strength discontinuity (spatial and temporal variability of material parameters) and the relative compaction instead of bulk density. Scarcity of experimental data on the heterogeneity is a constraint in modeling the effects of soil compaction. Further work is needed to develop modeling approaches with consideration of soil structural discontinuities and spatial variation of the input parameters resulting from compaction.

Soil erosion models broadly fit into two groups: empirical and process-based models (see *Soil Erosion Modeling*). The Universal Soil Loss Equation (USLE) (Wischmeir and Smith, 1978) is the most dominant empirical model to predict field-scale erosion rates.

Crop models are mostly based on physiological and climate data without consideration of soil structure (Walczak et al., 1997). To bridge this gap, investigations were carried out in 1992–1995 within the framework of international multilateral projects between Austria, Czech Republic, Hungary, Poland, and Slovak Republic on the role of soil structure functions for sustainable agricultural biomass production and soil protection (International Agrophysics, Special issue, 1993, Vol. 7, Nos 1–3 and Special issue, 1997, Vol. 11, Nos. 1–2). From the analysis of the models considering soil processes, it resulted that the soil structure parameters appearing most frequently in them are soil water retention, root system parameters, soil compaction and porosity, and unsaturated and saturated water conductivity. Generally, models of plant production include two groups of parameters: soil parameters and plant parameters. At least growth stage and rooting depth are necessary as plant parameters if crop growth should be coupled with soil structure effects. Modeling showed clearly that the effect of the saturated water conductivity and bulk density on crop yield alone was not significant. But, as soon as root distribution was introduced as a plant parameter, a strong effect on the plant growth was detected as an overall consequence of the soil structure status. Physical soil parameters provide the same kind of methodological troubles as all other scientific measurements. But, there is an additional difficulty, which is the fact that structure-dependent parameters cannot be determined from composite, disturbed samples. Each core sample or each in situ measurement has to be treated separately. This creates very specific problems of sampling. However, almost all crop production models assume that soil is a homogeneous substrate. Therefore, it is very important to develop models which also consider soil heterogeneity, time, and spatial variability of soil parameters at various scales.

Food processing technology using innovative strategy needs support from models. Within the EU 7th Framework Program, the multidisciplinary European DREAM project (Design and development of REAlistic food Models with well-characterized micro- and macrostructure and composition) is being created at INRA (France) (Ad Litteram, 2009). The physical and mathematical food models developed as a result of the project will serve "as standards that can be applied across all major food categories to facilitate the development of common approaches to risk assessment and nutritional quality for food research and industry." Also post-harvest and processing technologies need mathematical models and optimization methods (De Baerdemaeker and Vandewalle, 1995; Agbashlo et al., 2009).

Even models which describe correctly the physical processes in modeled object may not yield accurate results when reliable values of the physical parameters of modeled object are not known. Even if the model has been widely used, uncertainties still arise when it is applied to conditions different than those for which the model was previously tested. Therefore, experimental verification of the model is very important (Fernandez et al., 2004).

Monitoring

Monitoring is the collection of data that allow to determine temporal and spatial variations of physical conditions in agriculture and the environment (see *Monitoring Physical Conditions in Agriculture and Environment*). The increasing pressure on natural resources, sustainability and exhaustion of nonrenewable resources need monitoring which should provide sufficient data for the decision makers. Advances in sensors, computers, and communication devices make it easier to collect useful information about physical conditions in agricultural and natural environment.

Recently, remote sensing technology is rapidly developing for monitoring the world's agricultural production including crop identification, acreage, vigor, density, maturity, growth rates, and yield forecasting, as well as soil physical properties and water availability and quality (see *Remote Sensing of Soils and Plants Imagery*; *Soil Physical Degradation: Assessment with the Use of Remote Sensing and GIS*).

Research needs and challenges

We present some research needs and challenges to improve agrophysical knowledge and applications.

Soils

Capture the dynamics of soil structure effects and improve quantitative description of surface roughness, crusting, bypass flow, infiltration, deformation resistance (mechanical impedance, crop establishment).

Estimate of the effective soil physical properties of heterogeneous field soil profiles. Integration of directly measured data and indirectly estimated information derived from new noninvasive techniques such as neutron and X-ray radiography, magnetic resonance imaging, electrical resistivity tomography, ground penetrating radar. Microwave remote sensing seems promising for this.

Quantify the size, continuity, orientation, and irregularity of pores by means of image analysis for a broad range of agrophysical applications including water movement and solute transport following human activity.

Visualize and quantify the complex geometry of the pore network and soil structure in 3D on various scales, thus enhancing understanding of the multiple interacting soil physical, biological, and biogeochemical processes, including flux phenomena.

Quantify coupled soil heat and water transfer (particularly vapor flow components) and associated implications at various scales.

Integrate soil mechanical and conductive (hydraulic) processes affecting the time-dependent strain and the alteration of pore functioning, e.g., aeration and water fluxes. Precompression stress reflects well the stress and strain state for a given predrying intensity and helps the specification of appropriate agricultural machinery to avoid excessive soil and subsoil compaction.

Develop noninvasive soil sensors to alleviate the difficulty in researching below-ground processes (e.g., root development, water movement etc.).

Soil–plant relations

Explain perception of soil physical stress by plants (or plant roots) and the conversion of physical and chemical phenomena into physiological responses.

Determine the combined effects of multiple stresses such as water stress, oxygen stress, and mechanical stress, salinity, and temperature extremes on plant performance.

Develop emerging area of 3D soil–plant functional interactions modeling based on root architecture which allow better understanding of the complex mechanisms controlling water and nutrients fluxes in the soil–plant continuum and increase root uptake efficiency. Advances made in noninvasive measurement techniques can be useful for this.

Evaluate coacting effects of increasing temperature and associated changes in soil moisture and rising atmospheric CO_2 on SOM and plant productivity, due to future climatic change.

Manage landscape structure to optimize the use of solar energy, heat and water balance of agricultural areas toward increasing potential for sustainable production of biomass.

Breed plants to develop crop varieties for physically stressed environment, e.g., lodging.

Agricultural products and foods

Determine optimal physical conditions to increase the utility (technological) value during processing and storage.

Improve technology of harvesting, storing and processing to decrease qualitative and quantitative losses using physical methods and modeling approaches.

Deepen knowledge on physical properties through description of macroscopic and microscopic structures and processes.

Technology

Save energy during various technological processes used in agriculture.

Improve construction of machines and devices (equipped with electronics) used in agriculture in terms of effective energy use and environmental protection.

Data use

Develop complete and reliable databases of agrophysical data – a challenging task. They are an invaluable resource for researches, educators, practitioners, and policy makers, and present great opportunities to translate the existing data to the data we need using cost-effective pedotransfer functions (or model approaches).

Develop modeling approaches with consideration of structural discontinuities and spatial variation of the input parameters.

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Cross-references

Agrophysical Objects (Soils, Plants, Agricultural Products, and Foods)
Agrophysical Properties and Processes
Climate Change: Environmental Effects
Mineral–Organic–Microbial Interactions
Monitoring Physical Conditions in Agriculture and Environment
Plant–Soil Interactions, Modeling
Soil–Plant–Atmosphere Continuum
Soil–Wheel Interactions

AIR ENTRY VALUE

The value of water content or potential at which air first enters a porous media.

AIR FLUX (RESISTANCE) IN PLANTS AND AGRICULTURAL PRODUCTS

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Synonyms

Airflow–pressure drop relationship; Resistance to airflow

Definition

The resistance, which has to be overcome by air flying through porous media such as plant tissues and a packed bed of plants and agricultural products (e.g., bulk grain), is defined as a pressure drop per unit depth.

When air is forced through a layer of porous materials, resistance to the flow, the so-called pressure drop, develops as a result of energy lost through friction and turbulence. The prediction to airflow resistance is necessary, for example, to the fan selection for grain drying and aeration systems.

Ergun's model is the most comprehensive model to be used for airflow–pressure drop calculations. Ergun assumed that the pressure loss can be treated as the sum of the viscous and kinetic energy losses. The model is the sum of equation for laminar flow (this term is a linear function of airflow rate) and equation for turbulent flow (this term is a function of ${v_0}^2$) and has the following form:

$$\Delta P = 150\frac{v_0\mu}{d_e^2}\frac{(1-\varepsilon)^2}{\varepsilon^3} + 1.75\frac{\rho v_0^2}{d_e}\frac{(1-\varepsilon)}{\varepsilon^3} \quad (1)$$

where ΔP is the pressure drop per unit height, v_0 is the superficial velocity, d_e is an equivalent particle diameter, ε is the bulk porosity, μ is the dynamic viscosity of air, and ρ is the air density. The factors that affect the resistance of porous materials to airflow are among others: material porosity, size distribution of particles and pores, irregularity in particles and pores shape, surface roughness characteristics, orientation of the particles, and tortuosity. Such variables are extremely difficult to measure. For this reason, an empirical approach is often used.

Factors in Ergun's model other than airflow can be lumped into two parameters, so the model becomes an equation with the following form:

$$\Delta P = A_1 v_0 + B_1 v_0^2 \quad (2)$$

where A_1 and B_1 are product-dependent constants obtained from the experiment. When the velocity is small enough ($v_0 < 0.01$ m s^{-1}), viscous forces dominate the flow and the equation reduces to Darcy's Law ($\Delta P = A_1 v_0$). The Shedd's equation represents the airflow resistance data over an airflow range of 0.005–0.3 m s^{-1} and has the following form:

$$\Delta P = A_2 v_0^{B_2} \quad (3)$$

where A_2 and B_2 are product-dependent constants obtained from the experiment. The constant B_2 lying between 1 and 2 is a compromise between the velocity (v_0) and the (${v_0}^2$) terms in Ergun's model. Hukill and Ives' equation:

$$\Delta P = \frac{A_3 v_0^2}{\ln(1 + B_3 v_0)} \quad (4)$$

where A_3 and B_3 are product-dependent constants obtained from the experiment, is valid for airflow range of 0.01–2.0 m s^{-1}.

Effects of process parameters on the resistance of, for example, bulk grain and seeds to airflow are generally the following: (1) the resistance to airflow decreases with an increase in product moisture content, (2) dense filling results in an increase in pressure drop, (3) the resistance to airflow through a bed of product in the horizontal direction is, in most cases, smaller than in the vertical direction, (iv) a product mixed with foreign materials offers more resistance to airflow than cleaned one.

Further details are given by Smith (1995) and Pabis et al. (1998).

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Cross-references

Aeration of Agricultural Products
Aeration of Soils and Plants
Drying of Agricultural Products
Grains, Aerodynamic and Geometric Features

AIR HUMIDITY

The amount of water vapor within the atmosphere.

AIR POROSITY

A volume of a material (e.g., soil, plant) that is occupied by pore spaces.

ALGAE, THE POTENTIAL SOURCE OF ENERGY

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Definition

Algae are a large and diverse group of simple photosynthetic microorganisms. They live in different environments: such as water, soil, but also on snow, and on ice. Algae are very sensitive to different factors, so they can be used as biological and pollution indicators. Algae are useful as fertilizer, important source of food – especially in Asia – and in bioremediation applications. They contain very important chemical compounds, so can be used in industry, especially for cosmetics and pharmaceuticals.

In aspect of the potential energy source, microalgae are sunlight-driven cells that convert carbon dioxide to potential biofuels and high-value bioactivities. Microalgal biomass contains three main compounds: carbohydrates, protein, and natural oils and can provide several different types of renewable biofuels:

- Methane produced by anaerobic digestion of the algal biomass
- Biodiesel derived from microalgal oil
- Ethanol produced by fermentation
- Photobiologically produced biohydrogen

Economics of the fuel production from algae demands that all the biomass is utilized as efficiently as possible. The most simplistic method is methane gas production. Biological and thermal processes are involved in gasification of organic carbon into methane. Ethanol production is most effective for conversion of the carbohydrate fraction. Biodiesel production applies to the natural oil fraction.

The idea of using microalgae as a source of fuel is not new, but it is being taken seriously because of the escalating price of petroleum. The production of microalgal biomass is carried out in closed photobioreactors or in open ponds. Closed photobioreactors have the benefits of better control over environmental conditions (pH, temperature) and biological contaminants and higher cell concentrations.

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ALKALINITY, PHYSICAL EFFECTS ON SOILS

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Synonyms

Basicity; Sodicity

Definition

Alkali or alkaline soils have been defined as soils with high pH-value, which is caused by excessive (usually more than 15% of the exchange sites) amount of exchangeable sodium ions or/and soluble salts capable of alkaline hydrolysis. The most injurious alkaline sodium compounds in the soils and irrigation waters are Na_2CO_3 (sodium carbonate) or $NaHCO_3$ (sodium bicarbonate).

Introduction

Natural and man-induced salt accumulation in the soil profile is a major environmental threat with dramatic negative impacts on agricultural production and sustainability, especially in the arid and semiarid regions of the world.

Alkalinity problems are more common in clay soils than in soils with low colloid content. As a consequence of the relative preponderance of sodium on exchange sites of colloids, the alkaline reaction of the liquid phase and the swelling/shrinking clay minerals, the low fertility of these salt-affected soils, in most cases, are closely related to their unfavorable physical and hydrophysical properties and their extreme moisture regime (Várallyay, 1981).

The sustainable use and management require adequate understanding of the processes causing structural, water regime, and water transport problems of these soils.

Indicators of alkalinity

Exchangeable sodium percentage is for characterizing the relative ratio of sodium in the exchangeable cation complex (ESP). It is defined as

- ESP = (exchangeable Na × 100/cation exchange capacity)
- ESP = (exchangeable Na × 100/Σ (exchangeable Ca + Mg + K + Na)

The exchangeable cations and the exchange capacity are expressed in milliequivalent per 100 g.

The sodium adsorption ratio (SAR) is for characterizing the sodicity of the soil solution or applied irrigation water. It is defined as

$$SAR = [Na^+]/([Ca^{2+}] + [Mg^{2+}])^{1/2}$$

The cations in liquid phase of soil or in irrigation water are expressed in milliequivalent per liter.

Besides the widely used alkalinity indicators, the direct determination of soda alkalinity (Soda%) is used for the examination and the qualification of salt-affected soils containing considerable amounts of salts capable of alkaline hydrolysis. The determination is carried out with a suspension of soil in distilled water. The suspension is titrated with 0.1M $KHSO_4$ till the red color of phenolphthalein disappears. The pH-value can also be an indirect indicator of sodicity. The finely dispersed calcium carbonate may cause slight phenolphthalein alkalinity up to pH 8.5, and above this value, the alkalinity is probably caused by sodium carbonate or bicarbonate (Darab and Ferencz, 1969).

Change of soil physical properties under the influence of alkalinity/sodicity

The influence of sodicity on physical properties varies with clay content and clay mineralogy. In soils with higher content of swelling/shrinking clay minerals, lower exchangeable sodium percentage (ESP) or soda content can cause a more significant physical effect (Shaw and Thorburn, 1985; Várallyay, 1981).

Soil structure properties

There is a general agreement among the soil scientists, that spontaneous clay dispersion and swelling are the major factors that disintegrate the structure of sodic soils.

The increasing dispersion and swelling of bentonite caused by sodium carbonate solution was demonstrated in laboratory experiments (Darab and Ferencz, 1969; Szabolcs et al., 1969). An important conclusion of these experiments is that swelling reached its maximum at a relatively low concentration of sodium carbonate (0.1% m/m), while at a higher concentration it assumed a nearly constant lower value.

The effect of increasing alkalinity (pH) or Sodium Adsorption Radio (SAR) on clay dispersion was confirmed by several experiments (Chen and Banin, 1975; Frenkel et al., 1978; Bauder and Brock, 2001). While there is an agreement on dispersive effect of sodium on clay minerals, the combined effect of organic material and ESP on the dispersion of clay has been the subject of discussion. Emerson (1954) demonstrated the dispersive effect of organic material in soils with high ESP. Oades (1984) explained the dispersive effect of organic colloids by decreasing the activity of calcium through complexation, and by increasing the negative charge on soil colloids. There are several positive results of experiments where organic materials such as green manure or compost have been used to improve the structure of sodic soils (Chand et al., 1977; Robbins, 1986; Singh and Singh, 1989; Barzegar et al., 1997). Solving this problem needs further researches because of the contradictory results regarding the effect of organic colloids on clay dispersion.

McNeal (1968) revealed that the swelling of soil colloids can be evaluated as an opposite effect of ESP and the salt concentration of the soil solution (EC). The increase of ESP or the decrease of EC causes the increase of the swelling factor. The effect of sodium salt is double. As electrolytes, the neutral sodium salts (NaCl, Na_2SO_4) coagulate the colloids. However as an exchangeable cation, sodium tends to favor dispersion. For the simultaneous evaluation of effect of sodicity and salinity the electrochemical stability index (ESI) was developed. ESI has been suggested as a good measure of dispersive behavior of soils (Hulugalle and Finlay, 2003).

We have only a few data relating to the direct measuring of the change in the pore volume and its distribution under the influence of increasing alkalinity.

Józefaciuk et al. (2002) investigated the effect of alkalization on the pore properties of the soil with sodium hydroxide solution of increasing concentration from 0.001 to 1 mol dm^{-3}. The macropore volume and radius, in general, increased with the increasing alkali concentrations. The mesopore volume in most cases decreased due to the treatments. In general, the average mesopore radius increased under lower concentrations of sodium hydroxide and decreased under higher concentrations.

Lebron et al. (2002) using thin-section-techniques established that the area of the aggregates decreased steeply in the ESP range of 0–5. In the ESP range of 6–55, the area of the aggregates did not change.

Várallyay (1981) investigated the effect of Na_2CO_3 on the water retention of soil. Due to the effect of Na_2CO_3, the water retention increased with the increasing alkali concentration within the whole suction range. The available moisture range (AMR) – calculated as the difference between the field capacity and the permanent wilting point – increased with the higher ESP values. From the results he concluded that in such cases the main limiting factor of the availability of water is not the low AMR, but the limited water transport.

Transport processes in soils

Surface sealing and crusting are the first impeding factors of water infiltration into the soil. Soil crusting is related to soil texture, organic matter, and sodium content. In arid and semiarid regions, the presence of crusted salt and sodium-affected soils is very common (Bauder and Brock, 1992).

There are several studies in which the decrease of saturated hydraulic conductivity (K) has been related to the increasing Na content (McNeal and Coleman, 1966; Frenkel et al., 1978; Várallyay, 1981; Shainberg and Letey, 1984; Suarez et al., 1984).

Lebron et al. (2002) measured a steep decrease of hydraulic conductivity in the ESP range of 0–5, over this ESP range the hydraulic conductivity did not change. Crescimanno et al. (1995) pointed out that could not be defined a critical ESP threshold relating to the effect of ESP on water transport properties, since there were an almost linear relationships between the soil physical properties and the ESP.

Várallyay (1981) measured the influence of Na_2CO_3 on the unsaturated water conductivity of the soil. The influence of Na_2CO_3 was stronger in the low suction range. The influence of Na_2CO_3 solution decreased with the increasing suction.

Rajkai et al. (1993) measured by means of tension infiltrometer much lower hydraulic conductivity on soil with ESP 15 than on soil with ESP 2 in case of similar clay content. In line with Várallyay's result, the water conductivity difference between sodic and non-sodic soil was higher at low than at high tension.

Consequently it can be established that infiltration and leaching (wet condition, low gradient) are more limited than the upward capillary flow (dry conditions, high gradient) promoting the salt and sodium accumulations in these soils in case of a shallow, saline groundwater.

There are only a few data relating to the effect of alkalinity on gas transport in soils. Stępniewski et al. (1992) measured the oxygen diffusion coefficient and air permeability at different moisture tension of clay soils and at different exchangeable sodium content. These aeration-related soil properties were much worse in the natric B, than in the A horizon. However, an exact quantifying of the relationship between alkalinity and aeration properties needs much more data.

Conclusions

Alkalinity indicates very unfavorable physical properties of soils, especially in soils with high smectite-type clay content. The alkaline pH range and the ESP cause increasing dispersion and swelling of clay minerals. The role of organic colloids in the dispersion processes is not fully clarified. The structural deterioration in sodic soils causes a very limited water transport in the matrix of the wet soil. Salt accumulation can hardly be reversed due to the limited leaching in wet state of the soil. To the contrary, an accelerated bypass water movement can occur in dry state of the sodic soil due to crack formation. The structural and water movement properties of sodic soils are intensively investigated, but clarifying of some special transport properties (i.e., transport through the cracks and soil aeration properties) needs further researches.

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Cross-references

Aeration of Soils and Plants
Liming, Effects on Soil Properties
Shrinkage and Swelling Phenomena in Soils
Soil Aggregates, Structure, and Stability
Soil Hydraulic Properties Affecting Root Water Uptake
Soil Structure and Mechanical Strength
Soil Structure, Intersecting Surface Approach, and its Applications
Soil Surface Sealing and Crusting
Solute Transport in Soils

ALTERNATIVE SOURCES OF ENERGY FROM AGRICULTURE BIOMASS – A EUROPEAN PERSPECTIVE

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Introduction

Energy is the capacity of a physical system to perform work. Energy appears in many different forms, including chemical energy of fuels, heat, mechanical energy, and electricity, among others. These are related by the fact that conversion can be made from one type of energy to another.

Biomass is a renewable energy resource in the form of solid, liquid, or gas energy carriers. Solid biomass is used mainly for heat, liquid biomass for transport, and gas for electricity production. Biomass is regenerated by energy from the sun and through societal metabolism. In this context, biomass is material originating from vegetation (wood, straw, lignin liquid waste as black liquor, waste paper), from animals (municipal sewage sludge, manure, dung), and from substances that produce biogas (from anaerobic digestion of manure, sewage sludge, or organic solid waste on the sanitary landfills), bioethanol (from alcoholic fermentation of potatoes or crops), or pyrolytic gas (produced from wood or sewage sludge).

Organic waste material originating from animal metabolism may include biogas from the anaerobic digestion of animal manure or dung, biogas from anaerobic fermentation of sewage sludge in wastewater treatment plants, or biogas from anaerobic digestion of waste on the sanitary landfills. Organic material may be transformed into pyrolytic gas (mainly during the process of gasification of wood), and this pyrolytic gas may drive gas engines for electricity production or may be used in gas boilers for heat production.

Biomass is accumulated mainly in the place of production or processing of the plant material (e.g., surplus straw during the production of grain, waste wood in timber processing, and pulp in the paper industry), or it may be the plant material produced only for purpose of energy, for example, on the fast-growing, short-rotation tree plantations of selected poplar or willow clones.

Biomass is divided into two types of resources:

- Primary energy resources, including wood, straw, and sewage sludge (analogous to peat).
- Second-generation biomass that is a processed energy resource, upgraded into the form of biocarbon, biogas, bioethanol, biohydrogen, and pyrolytic gas.

Energy from photosynthesis

Plants have the ability to incorporate atmospheric carbon into biomass through photosynthesis. These molecules can then be used for fuel. This process is roughly exemplified by the following equation:

$$CO_2 + H_2O + PAR(8\ \text{quantum}) \rightarrow CH_2O + O_2 \quad (1)$$

where PAR is the photosynthetic active radiation (visible light) and 8 quantum of light is needed for transformation of 1 atom of C. The equation takes the form:

$$nCO_2 + nH_2O + \text{light} + \text{heat} \rightarrow C_m(H_2O)_n + nO_2 \quad (2)$$

The first "block" in building the biomass of plants is glucose, $C_6H_{12}O_6$ ($m = n = 6$), followed by more complex substances like polysaccharides ($m = n =$ tens/thousands), cellulose ($m > n =$ hundreds/thousands), and lignin ($m < n$ = hundreds/thousands).

In the past, black coal $(CH_2)_n$ was derived from biomass, but today, biogas $(CH_4)_n$, methanol $(CH_3OH)_n$, and biohydrogen (H_2) are derived. About 2 Mg of dry wood or straw are equivalent of the energetic value of 1 Mg of black coal. A fossil fuel like black coal has the parameters 25/22/0.8 (25 MJ/kg, 22% ash, 0.8% sulfur), but biomass from plant material (wood or straw) has the parameters 13/3/0.03. Dry sewage sludge has the parameters 14/45/0.8, which is similar to the contents of the coal waste mud produced during the process of washing of black coal or to the contents of low-quality lignite (brown coal) or dry peat. But in energy production such a material may be utilized, meaning that coal waste mud, low-quality lignite, peat, or dry sewage sludge are considered an energy resource in local solutions.

Energy crops

Energy crops can take many forms and can be converted to a number of different products (Canell, 2003; Sims et al., 2006). Many crop species are multipurpose in that they can be used to produce more than one type of energy product like oil, ethanol, and solid biomass, and they are classified as follows:

1. Oil crops (e.g., rapeseed, linseed, field mustard, hemp) – Vegetable oils can be used directly as heating fuel or refined into transport biofuels such as biodiesel esters.
2. Cereals (e.g., barley, wheat, oats, maize, rye, triticosecale) – Grain can be used to produce ethanol and the straw can be used as a solid fuel (after pelleting, if possible), or for biogas production from feedstock.
3. Starch and sugar crops (e.g., potato, sugar beets, Jerusalem artichoke) – Ethanol can be produced by fermentation, and then is used mainly in blends with gasoline.
4. Cellulose crops (e.g., straw, grass, wood, short-rotation coppice) – The hemicellulose can be reduced to sugar by acid or enzymatic hydrolysis and then fermented to produce ethanol in blends with gasoline or biogas (to produce electricity).
5. Solid energy crops (e.g., whole-crop maize, reed canary grass, silvergrass, willow, poplar) – These crops can be utilized as a whole to produce heat and electricity directly through combustion or indirectly through conversion for use as biofuels like methanol or ethanol.

Such classifications are very useful in the evaluation of the recent biomass market.

In agriculture, solid biomass can be produced from traditional crops like the straw of wheat, rye, or rapeseed, and from grasses. In the timber industry, sawdust and wood chips and shavings are used for biomass (wood used for fuel is usually smaller branches of trees and low-quality timber). From agribusiness, mill cake, brewery grains, promace of apples, bagasse, beet pulp, fruit stones, husks, molasses, paper, and pulp residues can be obtained.

More than 350 oil-bearing crops have been identified (Demirbas, 2007). Vegetable oils can be used directly or refined to biodiesel. The cereal grains can be used to produce ethanol, and straw can be used as a solid fuel. Sugar and cellulose crops can produce ethanol by fermentation, which is then either used directly or blended with fossil oil. Solid energy crops can be utilized only indirectly through conversion to biofuels. Some of the more common energy crops have been listed by Sims et al. (2006) and Tuck et al. (2006). Discussed here are crops already being grown in Europe or those, although allochthonous, with potentially high bioenergetic performances. Energy crops are annual and perennial plants, herbaceous or arboreous. Annual crops are mainly cereals or oilseed crucifers of the genus *Brassica*. Less important in terms of cultivated hectares in the EU are sugar beet (*Beta vulgaris* var. *saccharifera*), soybean, hemp, and flax. Perennial crops are herbaceous (e.g., silvergrass, Jerusalem artichoke, giant knotweed), shrubs (e.g., *Rosa multiflora*), or trees (e.g., willow *Salix spp*., poplar *Populus spp*., black locust *Robinia pseudoacacia*).

Biomass as a liquid transport biofuel in the form of oil or ethanol is very common. Two technologies exist on the market today. The first is the production of esters from rapeseed oil, creating so-called biodiesel. The second is the production of alcohol in the form of dewatered bioethanol mixed with ordinary gasoline (3.5% bioethanol, 96.5% gasoline) and distributed in the gasoline stations.

Liquid biofuels are produced from crops rich in oil, sugar, or starch. First-generation biofuels were produced as bioethanol from fermentation of maize or potatoes, or as the vegetation oils from rapeseed or soybean. Bioethanol with oil can be used to produce biodiesel, an ester of oils. The second-generation production of bioethanol is based on perennial plants (Reddy et al., 2008) such as switchgrass and silvergrass – these can provide 260% more ethanol per hectare than maize (Heaton et al., 2008) – or microalgae (Schenk et al., 2008) (see *Algae, the Potential Source of Energy*). The global yield for all biomass crops (both herbaceous and woody) ranges from 8 to 22 Mg of dry matter per hectare per year (Ragauskas et al., 2006).

The second generation of biofuels is biogas and biohydrogen. Biogas may be produced by anaerobic digestion in sewage sludge, animal manure, or solid waste dumps.

Biomass for energy in the European Union

According to terminology introduced in the European Union (Grassi et al., 1992; THERMIE, 1995), biomass includes all organic material of biological origin (mainly from vegetation), which may be produced on special energy plantations, or may come from the residues and waste products of forestry, timber production, municipalities, agriculture, and agribusiness (mainly the food-processing industry).

The sources of biomass in the European Union are wood from the fast-growing tree plantations, wood residues from forestry and timber production, manure and dung from animal production, straw produced along with grain, and organic waste in agribusiness during food processing. Organic material in the sewage sludge produced in the municipal wastewater treatment plants is also considered to be biomass. The producers of biomass for energy are agriculture (straw, biogas from animal manure), the forestry and wood processing industry (solid fuel wood), municipalities (waste paper, biogas from the sanitary landfills, or biogas from the wastewater treatment plants), or industry (residues from the paper and pulp industry, textile industry, food processing industry, etc.).

In the European Union, biomass has been identified as a vast potential reservoir of energy, comprising various organic raw materials of plant origin: forestry production, specific crops, and recycled agricultural, industrial, and household waste. Worldwide, it represents the fourth biggest energy resource (14% of global consumption) (see *Biomass as an Environmentally Benign Energy Source*). However, apart from Austria, Finland, and Sweden, where it plays a significant role, biomass accounts for only 2% of Europe's energy production. Biomass energy can be stored and does not fluctuate, and it has numerous advantages. It is neutral in terms of the greenhouse effect when used for electricity; plants give off the carbon dioxide that they took in while they were growing. A robust biomass industry has considerable potential for job creation and would provide a rationale for developing a common agricultural policy (European Commission, 2006, 2007).

Various European research projects involving conversion technologies (thermochemical, chemical, and biological processes) offer potential for diverse end-users, either as a source of heat and power or in the form of biofuels. Nevertheless, there are logistical problems involved in processing the large volumes of raw materials required to obtain sufficient and economical energy sources. At present, the cost of the energy produced is too high for many applications.

Oilseeds, cereals, starch crops, and solid biofuels will probably increase their growth in northern Europe by 2080, due to increasing temperatures, and will decrease in southern Europe due to increased drought (Tuck et al., 2006). These predictions indicate that the choice of bioenergy crops in southern Europe will be severely reduced in the future unless measures are taken to adapt to climate change.

Conclusion

Barriers to the use of biomass as an energy resource exist, including:

1. Lack of knowledge that the production of heat energy and electricity from cheap residual biomass is very economical and easily competes with conventional fossil fuels.
2. Low prices of conventional fossil fuels that don't account for the negative effects of coal, oil, and natural gas on the environment and human health.
3. Slow progress in the technological development of the most efficient production of heat and power from biomass.
4. Difficulties with the distributing the produced biogas or heat energy and electricity to the state-controlled gas pipe grid or electrical grid or to the district heating distribution pipes.
5. Lack of experience in implementing renewable energy in local energy plans for communities. The dissemination of knowledge about existing pilot programs and demonstration solutions is important. Until now, there have been a limited number of the success stories and positive solutions, but in the future there will be more examples of installations and commercial applications.

Production of heat and power from biomass is very promising if we take into account the existing positive demonstration plants. Biomass is much more environmentally friendly than any fossil fuel. The technical parameters of the boilers, the positive economical results and relatively short time to payback on investment, and the ecological benefits due to the low level of emission of pollutants into the atmosphere support the increased use of biomass as an energy source.

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Cross-references

Agroforestry Systems, Effects on Water Balance in Cropping Zone
Algae, the Potential Source of Energy
Biomass as an Environmentally Benign Energy Source

ALUMINO-SILICATE CLAY MINERALS

Clay minerals in which the crystal lattice typically consists of alternating layers of alumina and silica ions in association with oxygen atoms or hydroxide ions. Particles of such minerals typically exhibit negative surface charges, which are usually countered by adsorbed (exchangeable) cations.

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Cross-references

Clay Minerals and Organo-Mineral Associates

ANAEROBIOSIS

Occurring in the absence of molecular oxygen. (II) Growing in the absence of molecular oxygen (such as anaerobic bacteria). (III) in the absence of molecular oxygen (as a biochemical process).

Cross-references

Aeration of Soils and Plants
Oxidation-Reduction Reactions in the Environment

ANGLE OF REPOSE

The maximum angle the inclined surface of a cohesionless material can make with the horizontal.

ANION EXCHANGE CAPACITY

The total exchangeable anions that the soil can adsorb.

Cross-references

Surface Properties and Related Phenomena in Soils and Plants

ANISOTROPY OF SOIL PHYSICAL PROPERTIES

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Definition

Anisotropy is the property of being directionally dependent, as opposed to *isotropy*, which means homogeneity in all directions. It can be defined as a difference in one soil physical property along different directions.

Anisotropic soil does not have the same physical properties when the direction of measurement is changed. Commonly it is used in reference to soil structure, soil strength, and soil permeability changes with direction of measurement.

Causes

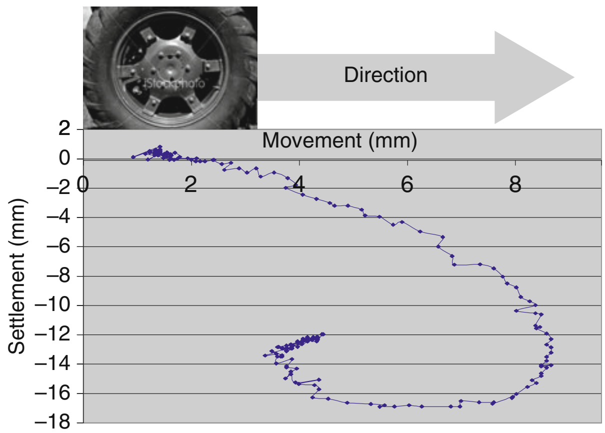
The anisotropy of soil physical properties may be primarily derived from natural pedogenesis. Due to the weathering of rock materials and the input of organic matter into soils, soil profiles can be, in general, defined as a humus-enriched mineral horizon (A), a leached horizon (E), an accumulated horizon (B), and a parent material horizon (C) from the topsoil downward to the less-weathered underlying material. The horizontal layers contain directly dependent soil properties. Human activity may be the secondary factor. Tillage creates a plow layer and a plow pan, which both exaggerate the predominantly horizontal-dependent soil properties. Soil cracks induced by soil shrinkage and swelling and biochannels may be another cause for a vertical-dependent soil structure and the permeability of gas and water. Soil physical properties, which are anisotropic, include soil structure (Pagliai et al., 2004; Dörner and Horn, 2006), soil strength (Peng and Horn, 2008), soil shrinkage and swelling (Bronswijk, 1990; Peng and Horn, 2007), and soil permeability of gas and water (Mualem, 1984; Dabney and Selim, 1987; Dörner and Horn, 2006), and so on. These properties, however, are further interacted each other. For example, the anisotropy of soil structure may result in the directionally dependent soil strength, soil permeability, and soil shrinkage and swelling.

Soil structure

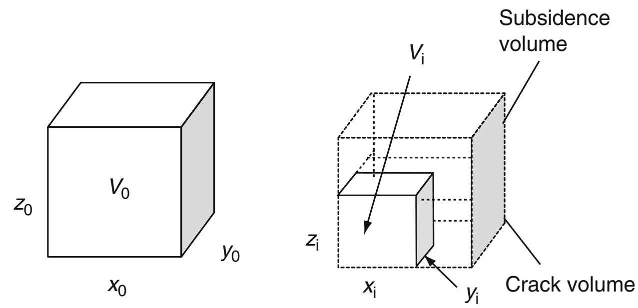
Hydraulic stress by natural wetting and drying cycles and mechanical stress by human tillage management always propagate three-dimensionally through the solid, liquid, and gaseous phases and result in a rearrangement of aggregates, their reformation, or complete destruction. In such case, the stress propagation is linked to an alteration of pore structure and excess soil water is drained off. During the natural wetting and drying cycles, new aggregate formation always starts with a prismatic structure of strongly vertically anisotropic behavior, later followed by a polyhedral and subangular blocky structure with a slight vertical anisotropic to isotropic behavior (Hillel, 1998; Horn et al., 2003). But, after tillage compaction, a platy structure can be formed (Pagliai et al., 2004; Dörner and Horn, 2006).

Soil strength

Mechanical stress from tractor wheeling causes a "kneading effect" of tires, which furthermore enhances an anisotropic soil structure (Figure 1). Aggregates or particles simultaneously move forward and downward. Therefore, the responses of pore structure and soil strength



Anisotropy of Soil Physical Properties, Figure 1 Particles move forward and downward simultaneously during tractor tire running.



Anisotropy of Soil Physical Properties, Figure 2 Volume change in vertical and horizontal direction by soil shrinkage.

to tractor wheeling resulted in anisotropic soil properties. Peng and Horn (2008) reported that agricultural machinery caused soil strength to be more anisotropic in conservation tillage than in conventional tillage.

Soil shrinkage/swelling

The anisotropy between the vertical and horizontal deformations during shrinkage and swelling was described by Bronswijk (1990) with the dimensionless geometry factor (Figure 2), r_s, defined by

$$r_s = \ln \frac{V_i}{V_0} / \ln \frac{z_i}{z_0} \tag{1}$$

where V and z are the volume and height of the soil, with the subscript 0 being the initial conditions and subscript i representing the ith step. There are five cases to describe their relationships: (1) $r_s = 1.0$, only vertical deformation; (2) $1.0 < r_s < 3.0$, predominant vertical deformation; (3) $r_s = 3.0$, isotropic deformation; (4) $r_s > 3.0$, predominant horizontal deformation; (5) $r_s \rightarrow \infty$, only horizontal deformation.

Based on the geometry factor, the anisotropy of shrinkage and swelling, increased with water loss and decreased upon wetting (Garnier et al., 1997; Chertkov et al., 2004; Peng and Horn, 2007). A conceptual model about the anisotropy of shrinkage and swelling was proposed by Peng and Horn (2007). At the beginning of drying, water is first drained from macropores by gravity, resulting in a small capillary pressure. The geometry factor shows only vertical shrinkage. As the soil dries further, water is removed from finer pores, causing greater capillary stress and both horizontal and vertical shrinkages. Vertical shrinkage dominates until the soil is dried intensively and only part of the very fine micropores still contains water. At this stage, the heterogeneous distribution of water preferably within soil aggregates and electrostatic attraction produces highly consolidated platy units. Due to the stress history on the soil the horizontal shrinkage becomes dominant instead of vertical shrinkage, while r_s is a little larger than 3. During swelling, however, the impact of overburden stress on vertical swelling results in the geometry factors exceeding 3.0 during the whole wetting process. At the beginning of wetting, the previously oriented platy soil particles, caused by the shrinkage history, produce the geometry factor greatly exceeding 3.0. If we evaluate the alteration of soil structure during wetting and drying, the shrinkage and swelling processes should be isolated.

Soil permeability

One of the consequences of anisotropic soil structure is a directly dependent permeability of gas and water. Earthworm and roots channels in the plowed layer both cause a preferential flux in a vertical direction (Wiermann et al., 2000; Peng and Horn, 2008). Vertical soil cracks also lead to a vertical predominance of soil permeability, whereas platy soil structure compacted by agricultural machinery induces a mainly horizontal flux (Dörner and Horn, 2006; Horn et al., 2003; Pagliai et al., 2004).

Summary

Anisotropy of soil structure induced either by pedogenesis or by human activity is a basic soil property in nature. However, its consequences have not yet received much attention, particularly when modeling the permeability of gas and water it is often simplified as isotropic. The concept and principle of anisotropic soil physical properties will improve our understanding of dynamic of soil structure and permeability and soil sustainable agricultural management.

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Ecohydrology
Shrinkage and Swelling Phenomena in Soils
Soil Aggregates, Structure, and Stability
Soil Structure and Mechanical Strength
Tillage, Impacts on Soil and Environment

ANOXIA AND HYPOXIA

Terms anoxia (absence of oxygen) and hypoxia (decrease of oxygen).

Cross-references

Aeration of Soils and Plants
Oxygenology

ANTHRIC SATURATION

This special, human-induced aquic condition occurs in soils that are cultivated and irrigated, especially by flood irrigation. Examples of anthric saturation would be rice paddies, cranberry bogs and treated wetlands.

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ARABLE LAND USE

See *Tillage, Impacts on Soil and Environment*

ATTENUATION

The process by which a compound is reduced in concentration over time, through absorption, adsorption, degradation, dilution, and/or transformation.

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ATTERBERG LIMITS

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Cross-references

Rheology in Soils

AVAILABLE WATER (CAPACITY)

The amount of water released between field capacity (at soil matric potential −33 kPa) and the permanent wilting point (usually estimated by water content at soil matric potential of −1.5 MPa).

Cross-references

Field Water Capacity
Soil Hydraulic Properties Affecting Root Water Uptake

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