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DOI: 10.2478/ssa-2013-0012

SOIL SCIENCE ANNUAL
Vol. 64 No 2/2013: 67–80

REVIEW PAPER

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Agrophysics – physics in agriculture and environment

Abstract: Agrophysics is one of the branches of natural sciences dealing with the application of physics in agriculture and environment. It plays an important role in the limitation of hazards to agricultural objects (soils, plants, agricultural products and foods) and to the environment. Soil physical degradation, gas production in soils and emission to the atmosphere, physical properties of plant materials influencing their technological and nutritional values and crop losses are examples of such hazards. Agrophysical knowledge can be helpful in evaluating and improving the quality of soils and agricultural products as well as the technological processes.

Key words: agrophysics, soils, agriculture, environment, physical methods

INTRODUCTION

Agrophysics is defined as "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" (Gliński et al., 2011a).

Agrophysics is an integral part of environmental physics. It deals with the processes in lands in agricultural use, being under intensive human intervention, e.g. monoculture crops, water management and high level of chemical and mechanical treatments. Agrophysics is also concerned with plant raw materials as a source of high quality agricultural products and food. It comprises physical processes and properties of soils, plants, agricultural products and food (Fig. 1, Table), measuring methods, modelling and monitoring.

Agrophysics has been developing dynamically in the last decades. It links knowledge in environmental physics (Monteith and Unsworth, 2007), soil physics (Scott, 2000; Chesworth, 2008), plant physics (Mohsenin, 1986) and food physics (Sahin and Sumnu, 2006) and fills the gap between such disciplines as agrochemistry, agrobiology, agroecology and agroclimatology. Agrophysical research plays a significant cognitive and practical role, especially in agronomy, agricultural engineering, horticulture, food and nutrition technology, and environmental management (Frączek and Ślipek, 2009). Application of agrophysical research allows mitigating chemical and physical degradation of soils, decreasing greenhouse gases emission to the atmosphere, reducing losses of agricultural products (plant raw materials, vegetables and fruits) during harvest and post harvest processes and storage, and improving agricultural products and food quality.

The development of agrophysics is confirmed by the quarterly journal International Agrophysics, published since 1986, and the Encyclopedia of Agrophysics (Gliński et al., 2011b).

The aim of this paper is to show role of agrophysics in the investigation hazards to agricultural objects (e.g. physical soil degradation, crop yield losses) and of physical properties of plant materials influencing their technological and nutritional values and the environment (soil-plant-atmosphere relations, soil physical conditions and plant growth, gas production in soils and emission to the atmosphere) with the use of modern measuring techniques, monitoring and modelling methods.

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TABLE. Main agrophysical processes and properties and their impacts on soil, plants, agricultural products and food (after Gliński et al., 2011a).

Physical processes	Physical properties	Impact on soil and plants	Impact on agricultural products and food
Mass transport (water, vapour, air and chemicals flow; capillary flow, molecular diffusion, osmosis)	Hydraulic conductivity, water diffusivity coefficient, vapour diffusivity coefficient, air diffusivity coefficient, chemicals diffusivity coefficient, permeability	Water available to plants, seepage, 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	Filtration, waste disposal, gas exchange, coagulation, flocculation, peptisation, shrinkage	Drying, hydration, dehydration, storage respiration
Energy transport (heat conduction, convection, radiation)	Thermal conductivity, thermal heat capacity, specific heat, permittivity	Thermal condition	Drying, processing, cooking
Energy absorption/emission (heat conduction, radiation)	Reflectance, absorption, permittivity, dispersion, colour composites, spectral vision	Thermal condition, albedo, growing degree-days	Drying, heating, processing

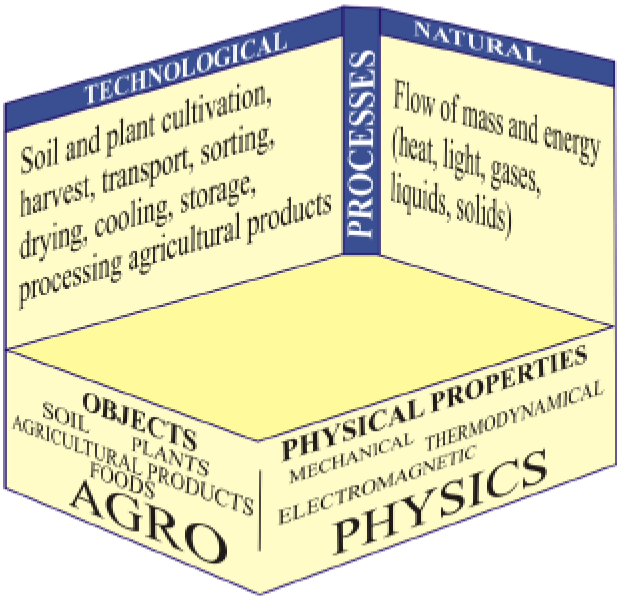

FIGURE 1. Scheme of the scope of agrophysics (after Gliński et al., 2011a)

SOIL PHYSICAL DEGRADATION

Soil physical degradation is involved in the wider definition of soil degradation "the general process by which soil gradually declines in quality and is thus made less fit for a specific purpose, such as crop production" (Soil Science Glossary Terms Committee, 2008). Soil physical degradation has negative impacts on nearly all soil characteristics and processes, e.g. space for plant roots and soil biota, soil temperature, transport of water, air and nutrients, as well as natural attenuation of organic and inorganic contaminants (Blum, 2011). Various processes of natural or human origin such as: erosion, compaction, pans, sealing and crusting, desertification waterlogging have physical character and their mitigation may be done also with the use of physical treatments (Białousz, 2011; Blum, 2011).

Soil erosion

Soil erosion is a globally significant environmental process. It degrades soil upon which we rely for food, fuel, clean water, carbon storage, and as substrate for buildings and infrastructure. Soil erosion also acts as a mechanism for transferring pollutants to surface waters and can reduce water availability for crops and increase flooding (Quinton, 2011).

Part of soil erosion processes is water erosion and wind erosion in which water and wind are erosive forces in soil detachment and transport. In consequence, soil productivity is lowering by decreasing its organic carbon content, infiltration capacity and retention of plant-available water. *Water erosion* is intensive on bare, temporarily unprotected arable land, overgrazed areas and badlands. In Europe soil loss due to erosion is estimated at about 20 Mg ha^{-1}; higher erosion rates up to 40 Mg ha^{-1} were noted in Africa and America (Rejman, 2011).

Wind erosion is caused by sand and dust storms and movement of shifting sand dunes in deserts or along coastlines (Gromke and Burri, 2011). Its effect is soil loss, leading to land degradation and desertification. It also affects the global dust particle concentration in the atmosphere. Wind erosion can be controlled by reducing the wind force at the soil surface by stripe cropping or by wind barriers, e.g. shelterbelts (Kędziora, 2011). Also production on the soil surface stable aggregates or clods resistant to wind force, and the use of chemical surface films are recommended. An example of human induced erosion is *tillage erosion* (Birkás, 2011; Zhang, 2011). It refers to soil translocation, especially on the hillslope, due to tillage operation and is an important process of soil degradation on sloping cultivated land. The change of tillage technique and farming system (Papadopoulos, 2011) mitigate erosion effects.

Soil compaction

Compaction causes soil structure destruction through the reduction of the volume of voids in a soil by packing the soil particles together (Assouline, 2011a). Soil compaction is an increasingly challenging problem for plant root growth, soil quality and the environment (Soane and Ouwerkerk, 1994; Horn et al., 2003). Most of soil compaction in modern agriculture is caused by vehicular traffic of agricultural implements, the size of which is progressively increasing. Soil compaction influences pore size distribution, its geometry, gas and water fluxes and, consequently, plant growth (Lipiec and Hatano, 2003; Dexter et al., 2008). In general, soil compaction decreases the contribution of large pores, total porosity, increases that of fine pores, and affects the pore continuity and the anisotropy of fluxes (Wójciga et al., 2009; Reszkowska et al., 2011). Agricultural machinery traffic can form an anisotropic soil pore system due to simultaneous movement of aggregates or particles forward and downwards and wheel slippage (Pagliai et al., 2003; Peng and Horn, 2008; Horn and Peth, 2011). Moreover, these processes result in an increased diversity of pore shape and roughness at the cluster or grain scales (Warkentin, 2000) and a platy structure with elongated pores that are oriented parallel to the soil surface (Horn et al., 2003). These soil structural changes directly affect soil water movement, gas exchange and heat transfer. Soil matrix with a finer pore size will result in excessive mechanical impedance encountered by roots, especially in dry soil, and in insufficient aeration in wet soil (Gliński and Lipiec, 1990; Whalley et al., 2000; Bengough et al., 2011).

Surface seals or crusts

Surface seals or crusts are relatively thin and hard layers on the surface of bare soils as a result of intensive rainstorms, percolation of runoff water rich in suspended solids, activity of nonvascular plants (Assouline, 2011b). Seals and crusts can induce severe agricultural, hydrological and environmental effects such as: decreasing infiltration rate, reduced evaporation, increasing runoff and decreasing crop yields.

Pans

Pans are genetic or induced by tillage operations subsurface soil layers of higher bulk density and lower total porosity than soil layers above and below the pan. These layers are slowly permeable. Clay pans, fragipans, hardpans, tillage pan, pressure pans, plough soles and traffic pans are synonyms of pans (Anderson, 2011; Busscher, 2011; Neyde Fabiola et al., 2011). Therefore pan soils are susceptible to water erosion and restrictive for root growth.

Desertification

Desertification is a permanent process of land transformation by natural processes, human intervention or a combination of both that may lead to the change of fertile soil into desert soil (Chesworth, 2008). Kuderma and Zsolnay (2011) proposed indicators and threshold levels of this process. Indicators are applied at different spatial (micro-, meso- and macro-) and temporal spaces (from minutes to years) which include soil (humus, microbiota, physics, hydrology), fields and plots (vegetation, fauna, erosion, surface waters) and catchments (socio-economics, ground water, climate). Degradation processes of soils play a significant role in drained *organic soils* (peats and mucks), drastically changing their volume by shrinkage during drying (Jaros, 2010).

Waterlogging

Waterlogging is an effect of the excess of water in soil, often due to flooding of the soil for varying periods of time during the year. Prolonged waterlogging affects anaerobiosis, causing damage of plant roots and enhancing reduction processes (low reduction potentials). It also affects the soil structure (Taboada et al., 2011).

One of the effective means to improve soil physical properties are *conditioners* (synthetic and waste-related structure forming agents) (Dębicki, 2011). They improve soil fertility and play an important role for environmental protection.

GREENHOUSE GAS EXCHANGE BETWEEN SOIL AND ATMOSPHERE

Gases such as CO_2, CH_4, N_2O are produced and consumed in soils mainly by microbial activity which is influenced by soil environmental factors such as; temperature, moisture, available carbon, nutrients, acidity and redox potential (Gliński et al., 2012). Gases are naturally sunk in soils (Włodarczyk, 2011), which is an important stabilisation of their concentration in the atmosphere at safety level. Soil is the major source of gases emission to the atmosphere and its transport within soil profile occurs by mass flow and diffusion. Efflux of gases to the atmosphere is influenced by barometric pressure fluctuations caused by the wind or air turbulence (Gliński and Stępniewski, 1985). The most important gas in the environment is CO_2 which in soil is produced during the process of soil respiration and evolved to the atmosphere (Gliński et al., 2010).

Soil respiration is the largest component of ecosystem respiration and varies with different ecosystem types (Luo and Zhou, 2006). The lowest CO_2 emission (about 80 g C m^{-2} yr^{-1}) was found in tundra, northern bogs and mires, medium (about 200–300 g C m^{-2} yr^{-1}) was found in desert scrub and boreal forests and woodlands, 400–700 g C m^{-2} yr^{-1} – in temperate grasslands, croplands, fields, temperate coniferous and deciduous forests, Mediterranean woodlands, tropical savannas and grasslands, tropical dry forests, and the highest rate (1260 g C m^{-2} yr^{-1}, on average) was found in tropical moist forests. In grasslands, soil carbon efflux was in the range from 400 to 500 g C m^{-2} yr^{-1} but in some circumstances may reach even 2100 g C m^{-2} yr^{-1}. CO_2 emissions from fresh water of wetlands to the atmosphere varied widely from 1.2 to 7.2 g C m^{-2} d^{-1}. CO_2 effluxes from peatlands had a very great range from 60 to 2100 g C m^{-2} yr^{-1}. In agriculture land the rate of soil respiration depends on the soil type and kind of crop cover and ranges from about 400 to 1200 g C m^{-2} yr^{-1} (Luo and Zhou, 2006). It reacts also to the treatments and cultivation methods. The increase in respiration rate in soil caused by the presence of plants amounts usually from 40 to 100% of the respiration of the soil alone (Gliński and Stępniewski, 1985). Hatano and Lipiec (2004), Hatano (2011) and Moreno et al. (2011) showed that after tillage CO_2 emission is enhanced by physical CO_2 release from soil due to reduced resistance to gas transfer. According to McGuire et al. (2001) losses of carbon from cultivated soils reach 0.8 Pg C yr^{-1} (812 g C yr^{-1}) globally. Production of CO_2 in soils and emission to the atmosphere is linked with global warming. According to Hatano (2011), an increase of global gas atmospheric concentration in the last century, mainly CO_2, increases radiative forcing warming the Earth. Another opinion is presented by Kutilek (2011) who suggests that the prediction of global warming cannot be based upon the results concerning greenhouse effects. Through the geological periods, the Earth surface, heated by solar radiation, emanated to the atmosphere long wave infrared radiation containing also human made “greenhouse gases”.

SOIL PHYSICAL CONDITIONS AND PLANT GROWTH

The changes in soil structure due to soil physical degradation will impose physical conditions influencing root growth and fluxes and thereby essential plant requirements such as adequate quantities of water, oxygen for aerobic respiration and nutritive elements (Gliński and Lipiec, 1990; Bengough et al., 2006). Crop responses to soil physical conditions depend on the growing stage.

Germination, emergence and crop establishment

The main soil physical requirements for germination and emergence include: temperature, water content, oxygen availability, soil strength and structure.

Temperature

In cold climates the rate of germination, emergence and final stand establishment is slowed greatly by low seedbed temperatures. The minimum temperatures for root growth are about 5°C. In hot regions, however, emergence can be hindered by adversely high seedbed temperatures. The maximum temperatures for root growth are from 35 to 40°C. The temperatures can be influenced by mulching (Harris, 1996; Townend et al., 1996).

Water

The water availability depends on soil characteristics which control how tightly water is held, seed-soil contact areas and evaporation. Finer-textured and well structured soils hold water more tightly than coarse textured soils with the same water content (Pachepsky et al., 2001). Irrespective of soil type, the plant-available water is between *in situ* field capacity and the permanent wilting point (water content at soil matric potential of – 1.5 MPa).

Aeration

Insufficient aeration for germination and emergence is usually caused by poor drainage and by a surface crust that can prevent gas exchange between the soil atmosphere and the air above. The effects of soil oxygen on seedling emergence differ between plant species and are better described in terms of oxygen diffusion rate (ODR) than in terms of oxygen concentration in the soil air (Gliński and Stępniewski, 1985).

Strength

Soil strength is an important constraint to seedling emergence and a cause of crop establishment failure. Excessive soil strength above developing seedlings can be induced by soil compaction due to machinery traffic at seedbed preparation and sowing, the presence of large clods and crust (surface hard layer) (Håkansson et al., 2002). The risk of poor emergence due to surface layer hardening depends much more on the sowing depth than on the aggregate sizes of the seedbed (Håkansson et al., 2002).

Structure

The influence of seedbed structure on crop establishment can vary greatly in terms of soil aggregation and subsequent pore size distribution that are largely influenced by cultivation. Optimum structural conditions for establishment occur between ranges for macroporosity of 10–19% and average pore size of 8–12 mm^2. It is clear that fine seedbed structures (<5 mm size) produce the greatest establishment (Håkansson et al., 2002; Atkinson et al., 2009).

Combined effect of soil physical characteristics on plants

The emergence and early crop growth may be limited by soil physical characteristics acting in combination (Lipiec et al., 2011). For example in the semiarid tropics, it can be large mechanical impedance, high temperature and water stress. However, in the cold and wet climate, limited early root and shoot growth can be a resultant of low temperature and oxygen deficiency. It is often difficult to determine the relative contribution of each characteristic.

Growth of established crops

The main soil physical factors influencing growth of roots and shoots of established crops include wa-

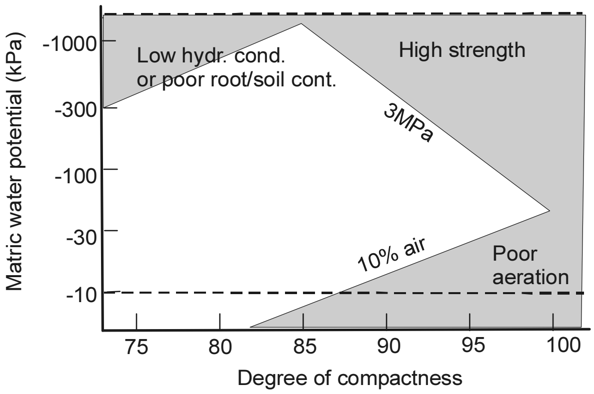

FIGURE 2. Relationship between soil strength of 3 MPa and air-filled porosity 10% (v/v) in relation to degree of compactness and matric potential of the plough layer. Crop growth in the upper left corner of the diagram are likely due to mainly low unsaturated hydraulic conductivity and/or poor root-to-soil contact (after Håkansson and Lipiec, 2000)

ter content, penetration resistance and aeration. They are largely affected by alterations in soil structure due to soil management practices (e.g. Czyż, 2004; Birkás, 2008; Usowicz and Lipiec, 2009). The penetration resistance of 3 MPa and air-filled porosity of 10% v/v are usually considered as critical for plant growth. As can be seen from Figure 2, the range of matric potential in which aeration and mechanical impedance do not limit root growth becomes narrower when the degree of compactness increases (Håkansson and Lipiec, 2000).

The range of soil water content in which aeration and mechanical impedance do not limit root growth is termed the least limiting water range (LLWR) (Da Silva et al., 1997). A soil matrix with a larger pore size, structural cracks, macropores and worm holes will offer greater potential for undisturbed root growth because the roots can bypass the zones of high mechanical impedance (Gliński and Lipiec, 1990; Lipiec et al., 2003).

Root-to-shoot signalling

When the soil physical properties suppress root growth and change root distribution, shoot growth and stomata functioning may also be reduced (Sweeney et al. 2006) as an effect of root-to-shoot signalling (Lipiec and Hatano, 2003; Dodd, 2005; Novák and Lipiec, 2012). Figure 3 indicates greater stomatal resistance of field-grown spring wheat in compacted than in non compacted soil, particularly in drought periods. The plant stress hormone abscisic acid (ABA) has long been recognised to act as a major chemical root-to-shoot stress signal under different environmental stresses (Zhang and Davies, 1989; Clark et al., 2005; Dodd, 2005; Schachtman and Goodger,

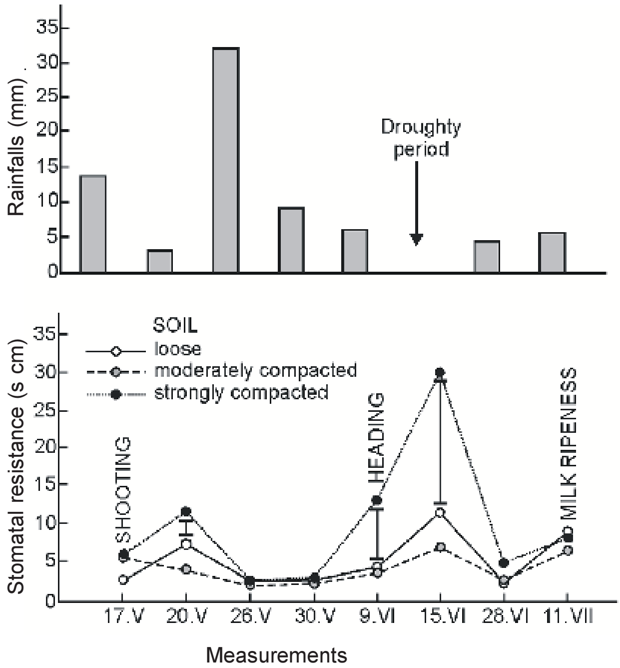

FIGURE 3. Stomatal resistance of spring wheat grown in field in relation to soil compaction (A) and rainfalls (B) (after Lipiec and Gliński, 1997)

2008). More work is needed to understand how the signalling capacity under environmental stresses differs in various genotypes.

Soil-plant-atmosphere relations

Soil-plant-atmosphere relations is the near-surface environment in which mass (water, nutrients, air) and energy (heat, light) transfer occurs from soil through plants to the atmosphere (Sławiński and Sobczuk, 2011). The system is composed of three main elements: solid soil constituents, water and air which are dynamic in time and variable in space. Soil plays the main role because it affects directly the availability of water and nutrients to plants. Plants in turn play the role of water transmission from soil to the atmosphere (Fig. 4).

The processes of mass and energy transfer which proceed within the soil-plant-atmosphere system are described with physical equations and modelling in different scales like leaf scale, canopy scale, landscape scale and mesoscale. From the practical point of view the knowledge of the system is helpful in prediction of yield quantity and quality and is also indispensable for irrigation system design and management.

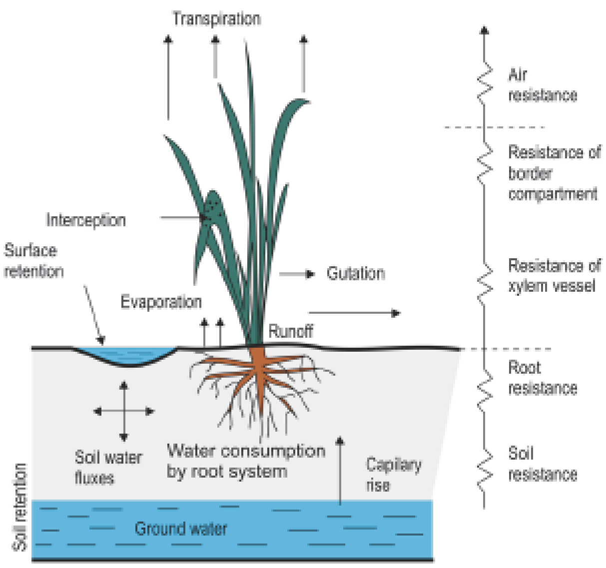

FIGURE 4. Water movement in soil-plant-atmosphere system (after Sławiński and Sobczuk, 2011)

PHYSICAL PROPERTIES OF PLANTS AND PLANT MATERIALS INFLUENCING THEIR TECHNOLOGICAL AND NUTRITIONAL VALUES

Raw materials of plant origin (cereals, partly fruits and vegetables) are mainly used as foods and food products after their processing. The knowledge of physical properties of such materials becomes very useful for the evaluation of their technological and nutritional values. A lot of papers were published to describe structural (shape, size, volume), mechanical, rheological, optical (colour), electrical and aerodynamic properties of agricultural plant materials. Examples on the above may be papers published in the last two years (2010–2011) in the journal International Agrophysics and contributions in the Encyclopaedia of Agrophysics (Gliński et al., 2011b) which present results on physical properties of many plants, also exotic ones from tropical regions, in relation to environmental conditions. The plants considered are: amaranth seeds (Sujak and Dziwulska-Hunek, 2010), apples (Ozturk et al., 2010; Zdunek et al., 2011), arigo (Davies, 2010), beans (Esehaghbeygi, 2010), cassava (Aviara et al., 2010), cucumber (Xinlin Li et al., 2011), hazelnuts (Ercisli et al., 2011), Jatropha (Fujimaki and Kikuchi, 2010), kariya (Ogunsina et al., 2011), lentil seeds (Bagherpour et al., 2010; Aladjadjiyan, 2010), maize (Izli and Isik, 2010; Amiri Chayjan et al., 2010; Frimpong et al., 2011), oil palm (Akinoso and Raji, 2011), pea (Kasprzak and Rzedzicki, 2010), raisin berries (Karimi et al., 2011), rape seed (Szot et al., 2011; Wiącek and Molenda, 2011), rice

(Emadzadeh et al., 2010; Askari Asli-Ardeh et al., 2010; Asthiani Araghi et al., 2010), roselle (Bamgboye and Adejumo, 2010), persimmon (Altuntas et al., 2011), saffron peach (Esehaghbeygi et al., 2010), tomato fruits (Gładyszewska et al., 2011; Zhiguo et al., 2011) or broader group of plants such as cereals (Dziki et al., 2010; Grundas et al., 2011; Khazaei and Ghanbari, 2010; Dziki and Laskowski, 2011; Obuchowski et al., 2010).

Physical properties as quality indicators of fruits and vegetables (Baiyeri and Ugese, 2011; Nelson and Trabelsi, 2011; Ruiz-Altisent and Moreda, 2011), grains (Kram, 2011) raw materials and agricultural products (Blahovec, 2011b; Dobrzański and Rybczyński, 2011; Lewicki, 2011; Horabik and Molenda, 2011) and food (Caurie, 2011; Moreda and Ruiz-Altisent, 2011; Scarlon, 2011) are also described, including the effects of drying process (Pabis et al., 1998; Karimi, 2010; Farkas, 2011b; Jayas and Singh, 2011; Gorjian et al., 2011; Kaleta and Górnicki, 2011a). Hlaváčová (2011) and Pietrzyk and Horyński (2011) present the electrical properties of agricultural products. The role of plant tissue microstructure in forming physical, chemical and biological properties of plants is given by Konstankiewicz (2011). A large database on physical properties of many plants and agricultural products can be found in an article by Kaleta and Górnicki (2011b).

CROP YIELD LOSSES

During the harvest and after harvest technologies, storage, drying and processing technologies of plant materials, there occur great losses of these materials which in some cases may exceed the amount of total yield and decrease the economic effects of plant production. The abovementioned actions include physical processes, knowledge of which may significantly decrease the losses of materials. How fundamental studies on the physical properties of plants (Rusin and Kojs, 2011) can reduce losses during harvest can be illustrated by the example of rapeseed which is a very economically important product (Szot et al., 2011). Studies concerned with the mechanical properties of rapeseed pods (cracking force and cracking energy), genetic traits, moisture, stage of ripeness, physical condition of canopy and variability of atmospheric conditions on the day of the harvest (Štekauerová, 2011) resulted in the improving harvest technology with the use of combine harvester and maximum limitation of quantitative and qualitative losses of seeds without any financial outlays (Fig. 5). Mechanical impacts of machines on crops at harvest and during post-harvest technologies cause their losses. Crop yield losses reduction needs rational use of machines through appropriate selection and control of their operating parameters and by selecting the best time for performing the technological processes. For these purposes the knowledge of physical parameters of plant material is very useful (Frączek and Ślipek, 2011). Plant lodging has a negative influence on the yield and its quality (Blahovec, 2011a; Podolska, 2011). Resistance of plants to lodging depends, apart from the chemical composition of plants (cellulose and lignin content), on their mechanical and structural properties (length and diameter of stems, thickness of cell walls and sclerenchyma width). The knowledge of these properties allows to breed new varieties resistant to lodging. Physical phenomena (mechanical, electrical, thermal, moisture) may be a direct cause of damage to agricultural products during their storage and may also induce chemical and biological processes that are harmful for the environment (Molenda and Horabik, 2011). Knowledge of

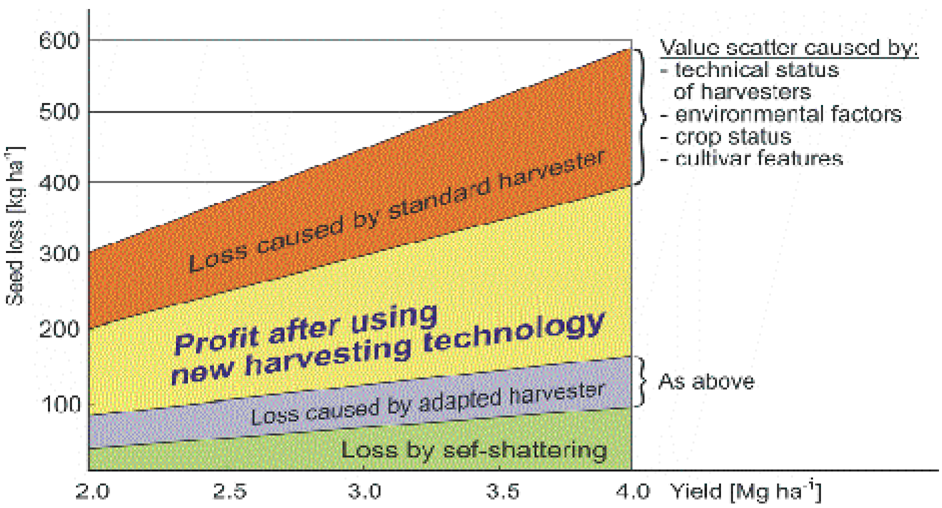

FIGURE 5. Relations between rapeseed seed losses and seed yields in combine harvest based on agrophysical research and effects of implementations at rapeseed producing farms (after Szot et al., 2011)

the physical properties of agro-food materials (seeds, grains, fruits and vegetables) such as shape and size, volume, density, porosity, surface area, strength, stress, hardness, toughness, elasticity, plasticity, brittleness and ductibility, is needed to protect them against losses (Łapko, 2010; Molenda, 2011). Thermal processing (ohmic, dielectric, infrared microwave, radio-frequency inductive) used in food industry includes the heating of food at defined temperature over certain periods of time (Vicente and Machado, 2011). Also improper processes of drying, dehydration and heating of agricultural products, without knowledge of their physical properties, may cause their thermal damage, loss of mass and poor sensory and nutritional quality of the end-products (Pabis et al., 1998; Karimi, 2010; Farkas, 2011a,b; Jayas and Singh, 2011; Kaleta and Górnicki, 2011a).

All the above mentioned phenomena of soil, plant material and environment degradation are studied with the use of modern physical measuring techniques, monitoring and modelling methods.

MEASURING TECHNIQUES, MONITORING, AND MODELLING USED IN AGROPHYSICAL INVESTIGATIONS

Measuring techniques, monitoring, and modelling are the main instruments in agrophysical investigations. Many advanced methods and measuring tools are used in agrophysics, *eg*. tomography, nuclear magnetic resonance (NMR), X-ray methods, ground penetrating radar (GPR), fractal analysis, image analysis, neural networks, particle film technology, relaxometry, remote sensing (Gliński et al., 2011b), optical technologies (Bieganowski et al., 2010). The collection of useful data for decision makers that allow to determine temporal and spatial variations of physical conditions in agriculture and the environment need monitoring (Skierucha, 2011). These conditions concern, among others, renewable resources, crop identification, growth rates and yield forecasting, determination of erosion and desertification acreage (area). Rapidly developing remote sensing technologies are very useful for such monitoring (Białousz, 2011; Salama, 2011).

Application of physical methods, laws and theories to agricultural problems allowed modelling of various natural processes in the environment or technological processes in agriculture and food production. The models used in application to life sciences are based on physics and mathematics. With regard to the way of description of processes, the physical models can be divided into: real models, analogue models, and phenomenological models (Mazurek et al., 1996). Mathematical models: mathematical-physical, statistical-physical, and mathematical-statistical can be used depending on the complexity of investigated processes. Phenomenological models are constructed when a real process is too complicated for a detailed physical-mathematical description (e.g., evapotranspiration, erosion, biomass production). Mathematical modelling may be used for different applications – from pure modelling of transport phenomena in soil to crop growth and yield prediction.

Mathematical-physical models are developed to describe soil, atmosphere, and plant processes responsible for biomass increase, using constitutional mathematical-physical equations (Van Genuchten, 1980). The equations result from the conservation laws, describing a chosen phenomenon in the 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 (Pukos, 1994; Walczak et al., 1997; Konstankiewicz and Pytka, 2008). A typical example of widely used mathematical-physical model is the mass and energy transport through the soil-plant-atmosphere system. It results from a combination of various mechanisms and includes molecular liquid diffusion, molecular vapour diffusion, capillary flow, convective transport, evaporation-condensation, pure hydrodynamic flow, and movement due to gravity. An example of vital tools to translate data that we have to data that we need in agrophysical research are pedotransfer functions (PTF), being equations or algorithms expressing relationships between soil properties different in the difficulty of their measurement or their availability. The PTFs are used to predict soil hydraulic properties (retention curve, hydraulic conductivity) from basic soil properties such as particle-size distribution, organic matter, and bulk density (Lamorski et al., 2008).

Post-harvest and processing technologies need mathematical models and optimization methods (De Baerdemaeker and Vandewalle, 1995; Agbashlo et al., 2009). Models using the discrete element method (DEM) and finite element method (FEM) for modelling physical processes in biological materials (e.g., plant tissue, Pieczywek et al., 2011; grain silos, Holst et al., 1999a,b; Wiącek and Molenda, 2011) seem to be very promising. Modern food processing technology needs food models with well-characterized micro- and macrostructure and composition to facilitate the development of common approaches to risk assessment and nutritional quality for food research and industry (Ad Litteram, 2009).

Models which describe properly the physical process in a particular object may not yield accurate results when real values of the physical parameters of modelled object are not known. Uncertainties still arise when modelling is applied to conditions different than those for which the model was tested. Therefore, experimental verification of the model is very important (Fernandez et al., 2004).

A LOOK AHEAD

Agrophysics has already a strong international position but it needs further research and challenges to improve knowledge and application.

For knowledge

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

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

Quantification of 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.

Visualising and quantifying the complex geometry of the pore network and soil structure in 3D on various scales is promising to enhance our understanding of the multiple interacting soil physical, biological and biogeochemical processes, including flux phenomena.

Quantification of coupled soil heat and water transfer (particularly vapour flow components) and associated implications at various scales.

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

Further research is needed to explain perception of soil physical stress by plants (or plant roots) and the conversion of physical phenomena into physiological responses.

Development of emerging area of 3-D soil-plant functional interactions modelling based on root architecture which allows better understanding of the complex mechanisms controlling water and nutrients fluxes in the soil-plant continuum and increase root uptake efficiency. Advances made in non-invasive measurement techniques can be useful for this.

Development of complete and reliable databases of agrophysical data is challenging. 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).

For application

Coupling of soil mechanical and conductive (hydraulic) processes affecting the time dependent strain and the alteration of pore functioning: e.g. aeration and water fluxes to help the specification of appropriate agricultural machinery to avoid excessive soil and subsoil compaction.

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

More research is needed in plant breeding to develop crop varieties for physically stressed environment, e.g. lodging.

Studies on the co-acting 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.

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

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

Improvement of technology of harvesting, storing and processing to decrease qualitative and quantitative losses using new physical methods and modelling approaches.

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

Saving energy during various technological processes used in agriculture.

Designing machines and devices (equipped with electronics) used in agriculture that will be economical in terms of their power (energy) and material requirements.

CONCLUSIONS

1. Agrophysical research carried out till now allowed to apply of physical laws and modern measuring methods to agricultural and environmental problems and already found their broad applications in environment protection, soil science, crop production, soil tillage, agricultural engineering and food technology
2. The use of physical laws and modern measuring methods in agriculture and natural environment allows us to forecast, estimate, monitor, mitigate, restrict and control unfavourable phenomena of physical degradation of soil environment and plant materials.

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Received: May 16, 2013
Accepted: August 5, 2013

Streszczenie: Agrofizyka jest integralną częścią fizyki środowiska, o charakterze interdyscyplinarnym, stojącą na pograniczu fizyki i biologii oraz nauk podstawowych i stosowanych. Odgrywa ważną rolę w ograniczaniu zagrożeń środowiskowych w obiektach rolniczych (gleby, rośliny, płody rolne, produkty żywnościowe) w tym: fizycznej degradacji gleb, produkcji i emisji gazów do atmosfery oraz strat ilościowych i jakościowych biomasy. Jest pomocna w ocenie i ulepszaniu gleb, produktów rolniczych oraz procesów technologicznych. Nowoczesne metody pomiarowe, monitoring i modelowanie odgrywają ważną rolę w badaniach agrofizycznych.

Słowa kluczowe: agrofizyka, metody fizyczne. gleby, rolnictwo, środowisko