Dominika ŚREDNICKA-TOBER[1], Agnieszka OBIEDZIŃSKA[2], Renata KAZIMIERCZAK[1], Ewa REMBIAŁKOWSKA[1]
[1] Warsaw University of Life Sciences (WULS-SGGW), Department of Functional and Organic Food and Commodities, Faculty of Human Nutrition and Consumer Sciences, Chair of Organic Food
ul. Nowoursynowska 159C, 02-776 Warszawa, Poland
[2] Institute of Agricultural and Food Economics, National Research Institute (IERiGŻ-PIB), General Economics Department
ul. Świętokrzyska 20, 00-002 Warszawa, Poland
e-mail: dominika_srednicka_tober@sggw.pl.

ENVIRONMENTAL IMPACT OF ORGANIC VS. CONVENTIONAL AGRICULTURE – A REVIEW

Summary

Nowadays nearly 40% of Earth's land is used by agriculture. Large areas of arable land are covered by cash crops monocultures, and most common intensive agricultural practices are highly dependent on water, synthetic mineral fertilizers, chemical pesticides, and increasingly also on the products of genetic engineering. The mentioned means of agricultural production, aiming at maximizing yields while decreasing direct production costs, resulted in the agriculture becoming in a very short time one of the economy branches with highly significant environmental impact. Some alternative agricultural systems have been developed in response to the increasing environmental and social concerns of intensive agriculture. One of such systems, earning growing interest worldwide, is organic farming. The presented paper shows and compares environmental impacts of organic vs. conventional agricultural production methods on the basis of available published research. According to the literature, global benefits of organic production methods include e.g. improvement of soil structure and fertility, reduction of soil degradation and erosion, protection of biodiversity, and increasing independence on external production inputs, in that water and non-renewable energy sources. All these features of organic production are important for protecting natural resources and fit well in the concept of sustainable development. It should be underlined that the mentioned environmental/ecosystem benefits of replacing industrial, intensive agriculture with the organic systems, translate into measurable economic values. However, as it is very difficult to internalize external (i.e. environmental) costs and benefits (e.g. ecosystem services) of agriculture, they are usually not taken into account in global economic evaluation of the systems, thus inhibiting development of organic sector.
Key words*: organic agriculture, conventional agriculture, farming, natural environment, biodiversity, sustainability.*

WPŁYW ROLNICTWA EKOLOGICZNEGO I KONWENCJONALNEGO NA ŚRODOWISKO NATURALNE – PUBLIKACJA PRZEGLĄDOWA

Streszczenie

Blisko 40% powierzchni lądowej Ziemi zajmują obecnie tereny użytkowane rolniczo. Większość gruntów ornych pokrywają wielkoobszarowe uprawy monokulturowe, a stosowane intensywne praktyki rolnicze zależne są w ogromnym stopniu od syntetycznych nawozów azotowych, środków chemicznej ochrony roślin, i coraz częściej także od technik inżynierii genetycznej. Wymienione środki produkcji, mające służyć maksymalizacji plonów przy równoczesnym ograniczeniu kosztów produkcji, mają swój udział w tym, że intensywne rolnictwo stało się w bardzo krótkim czasie jedną z gałęzi gospodarki o znaczącym negatywnym wpływie na środowisko. W odpowiedzi na negatywne konsekwencje środowiskowe i społeczne intensyfikacji produkcji rolniczej, pojawiły się alternatywne metody gospodarowania, w tym zyskujące dziś na znaczeniu rolnictwo ekologiczne. Niniejszy artykuł stanowi przegląd literatury naukowej podejmującej temat wpływu rolnictwa ekologicznego i konwencjonalnego na środowisko naturalne. Według dostępnej literatury, globalne korzyści wynikające ze stosowania ekologicznych metod produkcji rolnej to m.in. zwiększenie żyzności i poprawa struktury gleb oraz zapobieganie jej degradacji i erozji, ochrona bioróżnorodności, a także uniezależnienie produkcji od nakładów zewnętrznych, w tym przede wszystkim od nieodnawialnych źródeł energii. Wszystkie te cechy produkcji ekologicznej składają się na dbałość o trwałość naturalnych zasobów przyrodniczych i stanowią ważny element koncepcji zrównoważonego rozwoju. Należy podkreślić, że wymienione korzyści środowiskowe/ekosystemowe związane z zastępowaniem przemysłowego intensywnego rolnictwa przez system ekologiczny wiążą się z wymiernymi korzyściami ekonomicznymi produkcji rolniczej. Z uwagi na ich trudną internalizację, są one jednak często pomijane w globalnym rachunku ekonomicznym, co wpływa hamująco na rozwój sektora ekologicznego.
Słowa kluczowe*: rolnictwo ekologiczne, rolnictwo konwencjonalne, środowisko naturalne, bioróżnorodność, zrównoważony rozwój*

1. Introduction

Nowadays nearly 40% of Earth's land is used by agriculture [1]. Large areas of arable land are covered by cash crops monocultures, and most common intensive agricultural practices are highly dependent on synthetic mineral fertilizers, chemical pesticides, and increasingly also on the products of genetic engineering. The mentioned means of agricultural production, aiming at maximizing yields while decreasing direct production costs, resulted in the agriculture becoming in a very short time one of the economy branches with highly significant environmental impact. Some alternative agricultural systems have been developed in response to the increasing environmental and social concerns of intensive agriculture. One of such systems, earning in the last decades growing interest worldwide, is organic farming. The presented paper gives an overview of recently published research investigating the environmental impacts of intensive vs. organic agriculture.

2. Conventional/intensive farming & the environment

The use of modern, highly specialized agricultural machinery is often associated with cultivation of plants in large-scale monocultures requiring significant transformation of the agricultural landscape, including regulation of soil water conditions, surface leveling, removing woodlots, hedges and field margins. In many countries such a unified landscape is nowadays a dominant form of agricultural management. However, the mentioned landscape transformations lead to the destruction of natural habitats of many plant and animal species, resulting in a significant depletion of biodiversity in agricultural areas. Many studies show a significant loss of the diversity of wild plants, invertebrates and birds in heavily managed agricultural areas [2-5]. Depletion of flora and fauna species, and thus the disturbance of the natural balance in agrarian ecosystems promote the spread of pests and weeds, pushing farmers to the use of intensive chemical control on their fields. Widely used biocides do not operate selectively, leading eventually to the loss of soil life. Lack of natural balance of soil microbiota supports the growth of pathogenic microorganisms and the development of diseases. Moreover, the disturbance of biological processes in the soil leads to the organic matter loss [6-8]. Achieving desired yields under these conditions is only possible through the use of large quantities of easily soluble synthetic nitrogen, potassium and phosphorus fertilizers. An excess of these penetrates into groundwater, as well as flows into water ponds, lakes and rivers leading to eutrophication, anoxia and, in a consequence, to the gradual disappearance of life in these water reservoirs [9, 10]. The drastic degradation of freshwater and marine ecosystems observed today globally is strongly linked to a huge consumption of nitrogen and phosphorus fertilizers causing mentioned eutrophication of freshwater as well as developing areas of hypoxia in marine coastal waters [11, 12]. High dependence of crop yields on mineral fertilizers, while their production requires the use of scarce, non-renewable resources, is not a strategy ensuring long term, sustainable development of agricultural production. The scale of global use of synthetic NPK fertilizers and the most important environmental costs have been presented in Table 1.

Frequent use of heavy agricultural machinery in intensive farming is not only associated with high consumption of fuel, but also causes damage to the natural soil structure and increases its susceptibility to erosion. The results of numerous studies suggest that the biological activity of the soil, organic matter content, the stability of the structure and the associated erosion resistance, but also the yield per unit of applied fertilizer, decrease as a result of the use of intensive agricultural production methods [8, 20]. The previously mentioned chemical pesticides also pose a considerable threat to the environment, both because of their high toxicity, and the possibility of accumulation. Residues of many of these compounds contaminate ground and surface waters [10, 21] and climb to the top of the food chains by accumulating in tissues of living organisms [22]. This way they also get to the human body. The research results show high concentrations of organophosphorus pesticide metabolites in the urine of children consuming foods derived from intensive (conventional) farming [23, 24]. Moreover, it was observed that the pests, characterized by a very short life cycle, quickly become resistant to the active substances of pesticides. During several years these substances may lose their effectiveness, thus contributing to the strengthening of pest resistance [25]. Table 2 shows the scale of global pesticide use together with its external costs, in that the most important environmental and health impacts, and their economic estimations.

Table 1. Global use and the most important environmental concerns of synthetic NPK fertilizers

Category	Effects
Global use	800% increase in the use of synthetic nitrogen fertilizers the last 45 years [13, 14]. Global NPK use in the production season 2014/2015: 183 million tons [15].
Environmental costs [11-14, 16-19]	Pollution of soils, ground and surface waters, depletion of nonrenewable resources of N and P, loss of biodiversity, significant contribution to climate change (GHG emissions related to production, distribution and use of NPK fertilizers), soil acidification, negative impact on soil fauna, depletion of soil fertility, degradation of fresh water and costal ecosystems globally (eutrophication -> hypoxia -> anoxia)

Sources: own elaboration based on the cited studies

Table 2. Global use and environmental & health impacts of agricultural pesticide use, estimation of costs

Category	Effects
Global use [26]	3 million tons per year, with a total value of more than 40 billion USD
Biodiversity loss [27, 28]	Loss of the biodiversity of beneficial insects (in that natural pollinators including bees), freshwater and sea fish, birds, soil fauna etc.
Environmental pollution [27, 28]	Pollution of soils, ground and surface waters.
Human health [29-34]	Effects of occupational exposure (acute poisoning and chronic diseases of farmers and gardeners exposed directly to high doses of pesticides) and consumer exposure to low doses of pesticide residues in foods: cancers, neurodegenerative diseases, fertility disorders, endocrine disruption, immune disorders.
Other risks [35]	Development of pesticide resistance; poisoning and deaths of livestock
List of indirect costs of pesticide use [36]	Costs of drinking water pollution, decrease in fish population resulting from fresh water and sea water pollution, costs of water monitoring, costs of biodiversity loss, cultural losses, landscape losses, tourism losses, decrease in the population of natural pollinators, health care costs (acute and chronic toxicity of pesticides)
Estimation of indirect costs of pesticide use	USA: $ 9.6 billion/year [35] up to $ 39.5 billion/year [37]. UK: 350 million EUR/y; Germany: 200 million EUR/y; USA: 1.3 billion EUR/y (health risks of exposure not included in the calculations) [36]

Sources: own elaboration based on the cited studies

The described environmental and health impacts as well as their high economic costs, indicate a strong need for internalization of these external costs related to the agricultural use of pesticides. Inclusion of these costs in the price of chemical crop protection treatments would show how unprofitable their use is.

As already mentioned, the use of the genetic engineering methods is one of the directions of agricultural development. Gene manipulation techniques, used on an increasing scale, are aimed at obtaining plant varieties that are highly yielding regardless of the difficult climatic and soil conditions, as well as resistant to pests and tolerant to plant protection chemicals. The use of these and other genetic modifications is still controversial, as it is difficult to predict their environmental consequences. The studies published so far, aimed at investigating the impact of genetically modified foods on the consumers' health, also show conflicting results [38, 39]. Modifications by which crops acquire tolerance to herbicides resulted undoubtedly in a significant increase in the consumption of these chemicals with proven serious environmental and human health impacts [40]. Nowadays over 90% of the soybeans and corn cultivated in the USA are herbicide tolerant. Moreover, in a consequence of the introduction of herbicide tolerance genes to crop plants, the herbicide tolerance of weeds has been observed. The controversy also arises from the ethical and economic aspects of the cultivation of genetically modified plants. Biotech companies have the right to patent new varieties of transgenic plants obliging farmers to buy their seeds every year. The previously self-sufficient farmers become, in a consequence of the above actions, strongly dependent on biotech corporations dictating the terms of cooperation, i.e. prices of seeds [41].

When analyzing the environmental impact of agriculture, some aspects of livestock production should be addressed. Large-scale livestock farming widespread nowadays does not only mean low animal welfare standards (difficult living conditions, including inability to realize the natural needs and behaviors, as well as lack of sufficient living space), large consumption of high-energy feed concentrates, as well as synthetic feed additives accelerating weight gain [42-44]. Huge amounts of excrements difficult to manage on a limited space pose also a serious environmental hazard. High density of animals in a small area increases the risk of disease spreading. In a consequence, intensive livestock production is characterized by a high consumption of veterinary medicines, including prophylactically administered antibiotics.

For many decades these and many other risks associated with the intensification of agriculture were disregarded, as a focus was given primarily to the direct economic efficiency and yields. Nowadays it becomes accepted that the goal of agriculture should not be to produce more food, but to produce it where it is needed, using methods that respect the natural environment [45]. The last years brought some attempts to estimate the external costs of agricultural production, including its negative impact on the environment and human health, so that these costs could be incorporated e.g. in the price of production inputs. It is estimated that in the United States of America environmental and health care costs incurred as a result of the use of pesticides reach close to $ 10 billion per year [35]. Excessive consumption of synthetic fertilizers generates another $ 2.5 billion of costs, and another nearly $ 45 billion is attributed to the effects of the progressive soil erosion [46].

The high energy intensity of today's agriculture, as well as the strong dependence of the production on external inputs, including primarily oil, gas and water, is of a great concern nowadays. It is estimated that the total consumption of energy in the intensive agriculture is much greater than the amount of energy that is obtained in the yield. Moreover, the energy intensity of agricultural production goes hand in hand with the emission of greenhouse gases into the atmosphere [47, 48].

Today it is already known that agriculture is a sector with the largest share in the global greenhouse gas emissions, as well as contributing strongly to the loss of biodiversity, environmental pollution with agrochemicals and degradation of soil, which is undoubtedly one of the most valuable non-renewable resources on Earth [11, 49, 50]. Most of these environmental consequences are associated with the use of arable lands, accounting for nearly 12% of Earth's land [1], and each of them is associated with huge economic losses. In addition, the development of industrial, globalized agriculture, the aim of which was to ensure global food security, has led instead to a deepening of the problems related to providing access to food for the inhabitants of many regions of the world, especially developing countries. The rules of global trade and international structures that control the production and distribution of food, reduce significantly food sovereignty of many regions, inhibiting their growth and reducing access to food for their citizens.

The described consequences of modern intensive agriculture definitely question the possibility of its further development. Therefore, the challenge we face is how to ensure food security of the growing human population (which, according to the present forecasts, could reach 9-10 billion people by 2050), while maintaining the current values of the environment and protecting non-renewable resources [49]. The above concerns initiated the interest in alternative systems of agricultural production.

3. Organic farming as an alternative

As already mentioned, growing awareness of the environmental consequences of intensive agriculture have become a strong motivation to seek for more environmentally friendly alternatives. Organic farming is one of such solutions earning growing interest worldwide. The first forms of organic agriculture began to develop independently in different countries already in the twenties of the twentieth century. Today, the principles of organic farming in the European Union are defined in the Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labeling of organic products [51], which entered into force on 1 January 2009, repealing the previous Regulation No 2092/91 [52]. The detailed rules for its implementation are described in the Commission Regulation 889/2008 of 5 September 2008 [53].

According to the current Council Regulation (EC) No 834/2007 'production includes an overall system of farm management and food production that combines best environmental practices, a high level of biodiversity, the preservation of natural resources, the application of high animal welfare standards and a production method in line with the preference of certain consumers for products produced using natural substances and processes' [51]. In practice, this means that plants in organic farms are grown without the use of chemical protection treatments (insecticides, herbicides and fungicides), easily soluble synthetic NPK fertilizers and synthetic growth regulators. The high soil fertility in organic farming is gained through the use of natural organic fertilizers, green manure, and diversified crop rotation. Protection against pests and weeds is provided using the methods of biological and mechanical control. The diversity of the landscape in the organic farms, including a number of woodlots, field margins and ponds, ensures high biodiversity, and thus helps to maintain the natural balance in agricultural ecosystems, preventing invasions of pests and weeds.

Organic animal husbandry prioritizes animal welfare, ensuring adequate living conditions, including access to open air or grazing, realization of natural behaviors, as well as providing organically produced feeds of high quality. The choice of animal breeds is primarily driven by the ability of animals to adapt to local environmental and climatic conditions. In organic crop and livestock production the use of genetically modified organisms is forbidden. Moreover, organic farms are subjected to thorough inspections by accredited certification bodies, and their products are appropriately labeled, so that consumers can be sure about the origin and production methods of the organic foods. These and many other principles of organic agricultural production gave this system a huge interest and trust of a growing number of producers and consumers around the world. As a result, certified organic farming is now practiced by nearly 2.3 million farmers in 172 out of 227 countries of the world (in that by nearly 340,000 farmers in all 47 European countries), on the area of over 43.5 million hectares (27% located in Europe), and the market for organic products is one of the fastest growing food markets in the world, with global sales exceeding 80 billion USD per year [54]. The area of organic farmland has increased almost fourfold since 1999. Today it represents only 1% of all agricultural land in the world, but its share in the total agricultural area of the European Union is close to 6%, and there are countries where these values have already been considerably exceeded (Lichtenstein 30.9%, Austria 19.4% Sweden 16.4%, Estonia 16.2%, Switzerland 12.7%, Latvia 11.2%, Czech Republic 11.1%, Italy 10.8%). In Poland, the share of organic agricultural land in the total agricultural area accounts for 4.3%.

Among organic production systems there are those that go far beyond the rules defined in the legal regulations (i.e. aiming at closing nutrient cycles within the farm and becoming independent from any external inputs), and those in which farmers strictly follow the rules of current inspection and certification systems [55]. For many farmers, especially those with a production scale going beyond the purely local market, the organic farming certificates guarantee premium prices, compensating for higher workload and more expensive inputs, and thereby ensuring the economic efficiency of the farm. However, many farmers in both developed and developing countries, introduce the principles of organic production on their farms without being subject to certification, due to expanded bureaucracy associated with obtaining and maintaining certification. Even though, they grow their food while supporting the organic/ecological farming principles such as: food sovereignty (independence of food chains on transnational corporations), benefitting farmers and rural communities (ensuring economic stability and food security in rural areas), smart food production and yields, protection of biodiversity, sustainable soil health and cleaner water, ecological methods of pest control, promoting the development of a flexible food system (i.e. resilient to climate change) [56].

4. Environmental and social benefits of organic farming

According to the literature, global benefits of organic production methods include e.g. improvement of soil structure and fertility, reduction of soil degradation and erosion, protection of biodiversity, and increasing independence on external production inputs, in that non-renewable energy sources [57-70]. All these features of organic production are important for protecting natural resources and fit well in the concept of sustainable development.

Recently published systematic literature reviews and meta-analyzes have shown that in many aspects organic agricultural system is more environmentally friendly compared to the conventional system. Many studies point to a higher soil carbon, better soil quality and better protection of the soils against erosion in case of applying production methods following the principles of organic farming [57-63]. Moreover, organic farms are characterized by a much greater biodiversity of plants, animals (including pollinators, soil fauna, birds) and soil microorganisms and a greater landscape diversity compared to conventional farms [58-67]. According to the study reporting research results from eight European countries, insecticides and fungicides used in conventional agriculture have a negative impact on biodiversity in agricultural areas. What is more, insecticides have been found to reduce the effectiveness of biological pest control methods [68]. As in the organic farming the use of synthetic pesticides is prohibited, this system does not contribute either to the pollution of surface and groundwater with these compounds [58]. Organic farming is also associated with lower nitrogen and phosphorus leaching as well as significantly lower greenhouse gas emissions compared to conventional agriculture, when calculated per unit of area [58, 61, 63, 69, 70]. Given the size of the yields in both systems (on average lower yields in organic farms), the described effect is less pronounced, and sometimes opposite, per unit of product [61, 69, 70], but it should be mentioned that crop yields in organic farming are often comparable and in some circumstances (e.g. in case of drought) even higher compared to conventional agriculture [55]. Organic farming systems are also usually more energy efficient than conventional systems [58-60, 63, 66, 70], both per unit area and yield. Lower energy consumption of the organic farming [58-60, 66] and the greater amount of organic matter in ecologically cultivated soils [57-61] also contribute to the fact that this system is associated with reduced emissions of greenhouse gases (GHG) as well as with better soil carbon storage, and thus may be seen as a good alternative to intensive farming in face of global warming.

Table 3 shows main characteristics, aims and effects of organic compared to the conventional agricultural system.

It should be underlined that the mentioned environmental/ecosystem benefits of replacing industrial, intensive agriculture with the organic systems, translate into measurable economic values. However, as it is very difficult to internalize external (i.e. environmental) costs and benefits (e.g. ecosystem services) of agriculture, they are usually not taken into account in global economic balance of the systems, thus inhibiting development of the organic sector.

Table 3. Main characteristics, aims and effects of the conventional and organic agricultural production systems

Intensive / conventional farming	Organic farming
• High intensity of non-renewable energy use (agrochemicals, machinery, water pumping etc.); • High water consumption; • Large use of agrochemicals with detrimental effects on environment and human and animal health; • High dependence on synthetic NPK fertilizers; • No legumes in crop rotation; • Genetically modified organisms (GMOs) permitted; • Synthetic food additives permitted; • Aiming at maximizing the economical effectiveness of the production; • Higher yields (on average); • Higher GHG emissions per unit of area; • Decreased soil organic matter • Increased soil loss & erosion • Lower water holding capacity of soils • Less effective carbon storage in the soil • Loss of biodiversity in agricultural landscapes • Unified agricultural landscapes (monocultures) • Low animal welfare standards	• Low intensity of energy use (higher energy efficiency); • Lower water consumption; • Lower GHG emissions per unit of area; • No agrochemicals; • No synthetic fertilizers; • Organic fertilizers & crop rotation with legumes; • Maximizing the efficient use of local resources; • No GMOs; • No synthetic food additives; • Relying on farming practices based on natural ecological cycles; • Aiming at minimizing the environmental impact of the food sector; • Preserving the long term sustainability of soil; • Reducing the use of non-renewable resources. • On average lower yields (however, higher yields under conditions of water scarcity); • Reduced soil loss; • Increased soil organic matter; • Improved soil biochemical and ecological characteristics; • Improved soil water holding capacity; • More effective carbon storage in the soil; • Larger floral and faunal biodiversity • Diverse agricultural landscapes • High animal welfare standards

Source: own elaboration based on Gomiero et al. 2011 [62]

The authors of a study published recently in Nature [55] summarized the outcomes of available research attempting to estimate the external costs (including environmental costs), as well as external benefits (e.g. ecosystem services) of organic farming. Assigning a monetary value to the consequences of the agricultural land use (such as soil erosion and nitrate leaching which are much more pronounced in conventional production) points to an even greater profitability of organic farming [57-70]. It has been estimated that the conversion of conventional agriculture in the UK to organic farming would result in a 75% reduction of the total external costs of agricultural production (from approx. 1.5 billion to 385 million British pounds per year) [71]. Also the estimation of the external benefits of organic farming (i.e. ecosystem services such as biological pest control, protection against climate change, protection of biodiversity, water and soil quality etc.) shows the superiority of this production system over conventional agriculture. It was estimated that the inclusion of these benefits in the economic calculations is likely to completely offset the current price differences between organic and conventional agricultural products [72-74].

In addition to these environmental benefits, it must be stressed that organic farming supports food sovereignty of many regions, understood as the ability of societies to make independent decisions about their food production systems [75]. It favors production of food in small family farms, taking into account local environmental and social conditions. Moreover, it aims to reduce the length of the production and distribution chains, bringing together suppliers and consumers, which benefits the environment, but also guarantees independence of the local food chains in the era of strong food systems globalization.

These principles of organic farming contribute to the profitability of this system, not in a sense of generating global profits of big corporations, but by ensuring local producers a fair income and access to food. In many developing countries of Africa, Asia, Latin America and Oceania, where farmers still make up the majority of society, supporting the sustainable family farming contributes significantly to increasing of the effectiveness of food production and is the best way to ensure access to food to those who need it most. Poland is also one of the countries with a high social and economic importance of the agricultural sector. Therefore, supporting local organic production and consumption in Poland may significantly improve the living conditions of the rural population, provide new jobs and give the food system more independence from external factors. The described advantages of organic farming and the growing awareness of the threat of instability of the global food system based on intensive agricultural production may give an organic farming a significant role in ensuring food security, stability of the food system and the development of rural areas in Europe and other regions of the world in the coming years.

5. Limitations for the development of the organic sector

In many countries such as Poland, relatively young, insufficiently supported organic sector, is characterized by a poor organization of the internal market (the lack of a properly functioning production, processing and distribution chain). Additional difficulties may come from the bureaucratic and administrative barriers related to organic certification, relatively low income of consumers, as well as underinvestment of the activities towards the development of consumers' ecological awareness. All this means whose products from organic farms often end up on the market being sold as conventional, with no premium prices, and a limited group of consumers interested in organic foods purchase niche products paying high prices, generating income of distributors and wholesalers, and not farmers. The situation described above is a serious obstacle for a development of the organic sector.

5. Conclusions

The research findings published so far indicate clearly the environmental, social and economic potential of the organic agricultural system. However, there is a strong need for more research and for exploring and increasing the potential of organic farming for reducing the environmental impact of agricultural practices.

6. References

[1] FAOSTAT (2015): Food and Agriculture Organization of the United Nations FAOSTAT Online Database (accessed August 2015); http://faostat.fao.org/site/377/default.aspx#ancor.

[2] Stoate C., Boatman N.D., Borralho R.J., Rio Carvalho C., de Snoo G.R., Eden P. (2001): Ecological impacts of arable intensification in Europe. Journal of Environmental Management, Vol. 63, 337-365.

[3] Berry P., Ogilvy S., Gardner S., *Integrated farming and biodiversity. English Nature Report* A.U. English Nature, Peterborough, Editor 2004.

[4] Bengtsson J., Ahnström J., Weibull A. (2005): The effects of organic agriculture on biodiversity and abundance: a meta-analysis. Journal of Applied Ecology, Vol. 42, 261-269.

[5] Fuller R.J., Norton L.R., Feber R.E., Johnson P.J., Chamberlain D.E., Joys A.C., Mathews F., Steward R.C., Townsend M.C., Manley W.J., Wolfe M.S., Macdonald D.W., Firbank L.G. (2006): Benefits of organic farming to biodiversity vary among taxa. Biology Letters, Vol. 1, 431-434.

[6] Oehl F., Sieverding E., Ineichen K., Mader P., Boller T., Wiemken A. (2000): Impact of land use intensity on the species diversity of arbuscular mycorrhizal fungi in agroecosystems of Central Europe. Applied and Environmental Microbiology, Vol. 69, 2816-2824.

[7] Esjberg P., Petersen S., *Effects of reduced pesticide use on flora and fauna in the agricultural fields*, in *Pesticides research*, D.E.P. Agency, Editor 2002, Danish Environmental Protection Agency.

[8] Hartmann M., Fliessbach A., Oberholzer H.R., Widmer F. (2006): Ranking the magnitude of crop and farming system effects on soil microbial biomass and genetic structure of bacterial communities. FEMS Microbiology Ecology, Vol. 57, 3, 378-388.

[9] Carpenter S.R., Caraco N.F., Correll D.L., Howarth R.W., Sharpley A.N., Smith V.H. (1998): Nonpoint pollution of surface waters with phosphorus and nitrogen. Ecological Applications, Vol. 8, 559-568.

[10] Stolze M., Piorr A., Häring A., Dabbert S. (2000): The environmental impacts of organic farming in Europe. Org. Farm. Eur. Econ. Policy, Vol. 6.

[11] Rockstrom J., Steffen W., Noone K., Persson A., Chapin F.S., 3rd, Lambin E.F., Lenton T.M., Scheffer M., Folke C., Schellnhuber H.J., Nykvist B., de Wit C.A., Hughes T., van der Leeuw S., Rodhe H., Sorlin S., Snyder P.K., Costanza R., Svedin U., Falkenmark M., Karlberg L., Corell R.W., Fabry V.J., Hansen J., Walker B., Liverman D., Richardson K., Crutzen P., Foley J.A. (2009): A safe operating space for humanity. Nature, Vol. 461, 7263, 472-475.

[12] Steffen W., Richardson K., Rockstrom J., Cornell S.E., Fetzer I., Bennett E.M., Biggs R., Carpenter S.R., de Vries W., de Wit C.A., Folke C., Gerten D., Heinke J., Mace G.M., Persson L.M., Ramanathan V., Reyers B., Sorlin S. (2015): Sustainability. Planetary boundaries: guiding human development on a changing planet. Science, Vol. 347, 6223, 15.

[13] Bellarby J., Foereid B., Hastings A., Smith P. (2008): Cool Farming: Climate impacts of agriculture and mitigation potential. Greenpeace: Amsterdam.

[14] Davidson E.A., David M.B., Galloway J.N., Goodale C.L., Haeuber R., Harrison J.A., Howarth R.W., Jaynes D.B., Lowrance R.R., Nolan B.T., Peel J.L., Pinder R.W., Porter E., Snyder C.S., Townsend A.R., Ward M.H. (2012): Excess Nitrogen in the U.S. Environment: Trends, Risks and Solutions. Issues in Ecology Report No. 15. Ecological Society of America: Washington.

[15] IERiGŻ-PIB (2016): Rynek środków produkcji dla rolnictwa. Stan i perspektywy (red. A. Zalewski). IERiGŻ-PIB: Warszawa, Vol. 43.

[16] Wood S., Cowie A. (2004): A review of greenhouse gas emission factors for fertiliser production. IEA Bioenergy Task 38.

[17] Sutton M.A., Bleeker A., Howard C.M., Bekunda M., Grizzetti B., de Vries W., van Grinsven H.J.M., Abrol Y.P., Adhya T.K., Billen G., Davidson E.A., Datta A., Diaz R., Erisman J.W., Liu X.J., Oenema O., Palm C., Raghuram N., Reis S., Scholz R.W., Sims T., Westhoek H., Zhang F.S. (2013): Our Nutrient World: The challenge to produce more food and energy with less pollution. Global Overview of Nutrient Management. Centre for Ecology and Hydrology, Edinburgh on behalf of the Global Partnership on Nutrient Management and the International Nitrogen Initiative.

[18] UNEP (2014): UNEP Year book. Emerging Issues in Our Global Environment 2014. UNEP: Nairobi.

[19] Concepción E.D., Díaz M., Kleijn D., Báldi A., Batáry P., Clough Y., Gabriel D., Herzog F., Holzschuh A., Knop E., Marshall E.J.P., Tscharntke T., Verhulst J. (2012): Interactive effects of landscape context constrain the effectiveness of local agri-environmental management. Journal of Applied Ecology, Vol. 49, 3, 695-705.

[20] Maeder P., Fliessbach A., Dubois D., Gunst L., Fried P., Niggli U. (2002): Soil fertility and biodiversity in organic farming. Science & Culture, Vol. 296, 1694-1697.

[21] Porter W.P., Green S.M., Debbink N.l., Carlson I. (1993): Groundwater pesticides: interactive effects of low concentrations of carbamates aldicarb and methomyl and the triazine metribuzin on thyroxine and somatotropin levels in white rats. Journal of Toxicology and Environmental Health, Vol. 40, 1, 15-34.

[22] Wattiez C., *Links between in utero exposure to pesticides and effects on the human progeny. Does pesticide policy protect health?*, in *Congenital Diseases and the Environment*, P. Nicolopoulou-Stamati, L. Hens, and C.V. Howard, Editors. 2007, Springer Netherlands: Houten. p. 183-206.

[23] Lu C., Toepel K., Irish R., Fenske R.A., Barr D.B., Bravo R. (2006): Organic diets significantly lower children's dietary exposure to organophosphorus pesticides. Environ Health Perspect, Vol. 114, 2.

[24] Curl C.L., Fenske R.A., Elgethun K. (2003): Organophosphorus pesticide exposure of urban and suburban preschool children with organic and conventional diets. Environmental Health Perspectives, Vol. 111, 3, 377-382.

[25] Chrispeels M.J., Sadava D.E., *Strategies for pest control*, in *Plants, Genes, and Agriculture*1994, Jones and Bartlett: Boston M.A. p. 355-383.

[26] Popp J. (2011): Cost-benefit analysis of crop protection measures. Journal of Consumer Protection and Food Safety, Vol. 6, S1, 105-112.

[27] Choudri B.S., Baawain M. (2015): Effects of Pollution on Freshwater Organisms. Water Environment Research, Vol. 87, 10, 1679-1717.

[28] Damalas C.A., Eleftherohorinos I.G. (2011): Pesticide exposure, safety issues, and risk assessment indicators. International Journal of Environmental Research and Public Health, Vol. 8, 5, 1402-1419.

[29] Maqbool F., Mostafalou S., Bahadar H., Abdollahi M. (2016): Review of endocrine disorders associated with

environmental toxicants and possible involved mechanisms. Life Sci, Vol. 145, 265-273.
[30] Hernandez A.F., Menendez P. (2016): Linking Pesticide Exposure with Pediatric Leukemia: Potential Underlying Mechanisms. International Journal of Molecular Sciences, Vol. 17, 4,
[31] Sanchez-Santed F., Colomina M.T., Herrero Hernandez E. (2016): Organophosphate pesticide exposure and neurodegeneration. Cortex, Vol. 74, 417-426.
[32] Sengupta P., Banerjee R. (2014): Environmental toxins: alarming impacts of pesticides on male fertility. Human & Experimental Toxicology, Vol. 33, 10, 1017-1039.
[33] Dhouib I., Jallouli M., Annabi A., Marzouki S., Gharbi N., Elfazaa S., Lasram M.M. (2016): From immunotoxicity to carcinogenicity: the effects of carbamate pesticides on the immune system. Environmental Science and Pollution Research International, Vol. 18, 18.
[34] Corsini E., Sokooti M., Galli C.L., Moretto A., Colosio C. (2013): Pesticide induced immunotoxicity in humans: a comprehensive review of the existing evidence. Toxicology, Vol. 307, 123-35.
[35] Pimentel D. (2005): Environmental and economic costs of the application of pesticides primarily in the United States. Environment, Development and Sustainability, Vol. 7, 229-252.
[36] Leach A.W., Mumford J.D. (2008): Pesticide Environmental Accounting: A method for assessing the external costs of individual pesticide applications. Environmental Pollution, Vol. 151, 139-147.
[37] Bourguet D., Guillemaud T. (2016): The Hidden and External Costs of Pesticide Use. Sustainable Agriculture Reviews (ed. E. Lichtfouse), Springer: Switzerland, Vol. 19, 35-120.
[38] Mesnage R., Defarge N., Spiroux de Vendomois J., Seralini G.E. (2014): Major pesticides are more toxic to human cells than their declared active principles. BioMed Research International, Vol. 179691, 10, 26.
[39] Séralini G.-E., Clair E., Mesnage R., Gress S., Defarge N., Malatesta M., Hennequin D., de Vendômois J.S. (2014): Republished study: long-term toxicity of a Roundup herbicide and a Roundup-tolerant genetically modified maize. Environmental Sciences Europe, Vol. 26, 1, 1-17.
[40] Mesnage R., Defarge N., Spiroux de Vendomois J., Seralini G.E. (2015): Potential toxic effects of glyphosate and its commercial formulations below regulatory limits. Food and Chemical Toxicology, Vol. 84, 133-153.
[41] Ozturk L., Yazici A., Eker S., Gokmen O., Romheld V., Cakmak I. (2008): Glyphosate inhibition of ferric reductase activity in iron deficient sunflower roots. New Phytol., Vol. 177, 4, 899-906.
[42] Biavati B., Santini C., *Alternative therapies to reduce enteric bacterial infections and improve the microbiological safety of pig and poultry production systems*, in *Handbook of organic food quality and safety*, J. Cooper, U. Niggli, and C. Leifert, Editors. 2007, Woodhead Publishing Ltd.: London.
[43] Klocke P., Walkenhorst M., Butler G., *Reducing antibiotic use in organic dairy production systems*, in *Handbook of organic food quality and safety*, J. Cooper, U. Niggli, and C. Leifert, Editors. 2007, Woodhead Publishing Ltd.: London.
[44] Sundrum A., *Effect of organic husbandry and feeding regimes on pork quality*, in *Handbook of organic food quality and safety*, J. Cooper, U. Niggli, and C. Leifert, Editors. 2007, Woodhead Publishing Ltd.: London.
[45] FAO (2011): Global food losses and food waste – Extent, causes and prevention. Rome.
[46] Pimentel D., Harvey C., Resosudarmo P., Sinclair K., Kurz D., McNair M., Crist S., Shpritz L., Fitton L., Saffouri R., Blair R. (1995): Environmental and economic costs of soil erosion and conservation benefits. Science, Vol. 267, 5201, 1117-1123.
[47] Pretty J.N., Ball A.S., Xiaoyun L.I., Ravindranath N.H. (2002): The role of sustainable agriculture and renewable-resource management in reducing greenhouse-gas emissions and increasing sinks in China and India. Philosophical Transactions of the Royal Society A, Vol. 360, 1741-1761.
[48] Aneja V.P., Schlesinger W.H., Erisman J.W. (2009): Effects of agriculture upon the air quality and climate: research, policy, and regulations. Environmental Science & Technology, Vol. 43, 12, 4234-4240.
[49] Godfray H.C., Beddington J.R., Crute I.R., Haddad L., Lawrence D., Muir J.F., Pretty J., Robinson S., Thomas S.M., Toulmin C. (2010): Food security: the challenge of feeding 9 billion people. Science, Vol. 327, 5967, 812-818.
[50] Amundson R., Berhe A.A., Hopmans J.W., Olson C., Sztein A.E., Sparks D.L. (2015): Soil science. Soil and human security in the 21st century. Science, Vol. 348, 6235, 7.
[51] Council Regulation (EC) No 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No 2092/91.
[52] Council Regulation (EEC) No 2092/91 of 24 June 1991 on organic production of agricultural products and indications referring thereto on agricultural products and foodstuffs (OJ L 198, 22.7.1991, p. 1).
[53] Commission Regulation (EC) No 889/2008 of 5 September 2008 laying down detailed rules for the implementation of Council Regulation (EC) No 834/2007 on organic production and labelling of organic products with regard to organic production, labelling and control.
[54] FIBL, IFOAM (2016): The World of Organic Agriculture. Statistics & emerging trends. Vol.
[55] Reganold J.P., Wachter J.M. (2016): Organic agriculture in the twenty-first century. Nature Plants, Vol. 2, 1-8.
[56] Tirado R. (2015): Ecological farming. The seven principles of a food system that has people at its heart. Greenpeace report.
[57] Gattinger A., Muller A., Haeni M., Skinner C., Fliessbach A., Buchmann N., Mader P., Stolze M., Smith P., Scialabba Nel H., Niggli U. (2012): Enhanced top soil carbon stocks under organic farming. Proceedings of the National Academy of Sciences USA, Vol. 109, 44, 18226-18231.
[58] El-Hage Scialabba N., Hattam C.E. (2002): Organic agriculture, environment and food security. Environment and Natural Resources Series No. 4, FAO, Rome, 258 pp.
[59] Kaspercyk N., Knickel K. (2006): A Global Perspective. Organic Agriculture: A Global Perspective (CSIRO), Vol. 259-294.
[60] Tuomisto H.L., Hodge I.D., Riordan P., Macdonald D.W. (2012): Does organic farming reduce environmental impacts? a meta-analysis of European research. Journal of Environmental Management, Vol. 112, 309-320.
[61] Mondelaers K., Aertsens J., Van Huylenbroeck G. (2009): A meta-analysis of the differences in environmental impacts between organic and conventional farming. British Food Journal, Vol. 111, 10, 1098-1119.
[62] Gomiero T., Pimentel D., Paoletti M.G. (2011): Environmental impact of different agricultural management practices: conventional vs. organic agriculture. Critical Reviews in Plant Sciences, Vol. 30, 1-2, 95-124.
[63] Lynch D.H., Halberg N., Bhatta G.D. (2012): Environmental impact of organic agriculture in temperate regions. CAB Review, Vol. 7, 10.
[64] Tuck S.L., Winqvist C., Mota F., Ahnström J., Turnbull L.A., Bengtsson J. (2014): Land-use intensity and the effects of organic farming on biodiversity: a hierarchical meta-analysis. Journal of Applied Ecology, Vol. 51, 3, 746-755.
[65] Kennedy C.M., Lonsdorf E., Neel M.C., Williams N.M., Ricketts T.H., Winfree R., Bommarco R., Brittain C., Burley A.L., Cariveau D., Carvalheiro L.G., Chacoff N.P., Cunningham S.A., Danforth B.N., Dudenhöffer J.-H., Elle E., Gaines H.R., Garibaldi L.A., Gratton C., Holzschuh A., Isaacs R., Javorek S.K., Jha S., Klein A.M., Krewenka K., Mandelik Y., Mayfield M.M., Morandin L., Neame L.A., Otieno M., Park M., Potts S.G., Rundlöf M., Saez A., Steffan-Dewenter I., Taki H., Viana B.F., Westphal C., Wilson J.K.,

Greenleaf S.S., Kremen C. (2013): A global quantitative synthesis of local and landscape effects on wild bee pollinators in agroecosystems. Ecology Letters, Vol. 16, 5, 1461-0248.
[66] Lotter D.W. (2003): Organic Agriculture. Journal of Sustainable Agriculture, Vol. 21, 4, 59-128.
[67] Crowder D.W., Northfield T.D., Strand M.R., Snyder W.E. (2010): Organic agriculture promotes evenness and natural pest control. Nature, Vol. 466, 7302, 109-112.
[68] Geiger F., Bengtsson J., Berendse F., Weisser W.W., Emmerson M., Morales M.B., Ceryngier P., Liira J., Tscharntke T., Winqvist C., Eggers S., Bommarco R., Pärt T., Bretagnolle V., Plantegenest M., Clement L.W., Dennis C., Palmer C., Oñate J.J., Guerrero I., Hawro V., Aavik T., Thies C., Flohre A., Hänke S., Fischer C., Goedhart P.W., Inchausti P. (2010): Persistent negative effects of pesticides on biodiversity and biological control potential on European farmland. Basic and Applied Ecology, Vol. 11, 2, 97-105.
[69] Skinner C., Gattinger A., Muller A., Mäder P., Flieβbach A., Stolze M., Ruser R., Niggli U. (2014): Greenhouse gas fluxes from agricultural soils under organic and non-organic management — A global meta-analysis. Science of The Total Environment, Vol. 468–469, 553-563.
[70] Lee K.S., Choe Y.C., Park S.H. (2015): Measuring the environmental effects of organic farming: A meta-analysis of structural variables in empirical research. Journal of Environmental Management, Vol. 162, 263-274.
[71] Pretty J.N., Ball A.S., Lang T., Morison J.I.L. (2005): Farm costs and food miles: An assessment of the full cost of the UK weekly food basket. Food Policy, Vol. 30, 1, 1-19.
[72] Kremen C., Miles A. (2012): Ecosystem services in biologically diversified versus conventional farming systems: benefits, externalities, and trade-offs. Ecology and Society, Vol. 17, 40.
[73] Andersson G.K., Rundlof M., Smith H.G. (2012): Organic farming improves pollination success in strawberries. PLoS One, Vol. 7, 2, 15.
[74] Sandhu H.S., Wratten S.D., Cullen R. (2010): The role of supporting ecosystem services in conventional and organic arable farmland. Ecological Complexity, Vol. 7, 3, 302-310.
[75] Jones A.D., Fink Shapiro L., Wilson M.L. (2015): Assessing the Potential and Limitations of Leveraging Food Sovereignty to Improve Human Health. Frontiers in Public Health, Vol. 3, 263, 1-10.