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INNOVATIONS IN PLANT PRODUCTION AS AN OPPORTUNITY FOR POLISH AGRICULTURE

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Abstract. The ability to efficiently implement innovations in agricultural holdings, acquire knowledge, and to make effective use of biological progress in plant production are all challenges in modern agriculture. Globalization processes are a catalyst for innovation transfer as well as technical, biological, and organizational progress promotion. The ability to utilize innovations in Polish agriculture will be decisive for its development opportunities and competitive position at the international level.

Keywords: innovations in agriculture, biological innovations, progress, competitiveness

INTRODUCTION

Due to the rapidly changing world, enterprises must seek opportunities for gaining a competitive advantage. The introduction of innovative solutions in all the areas of economic activity is one of them. As a result, innovations and the innovation activity of enterprises in a broad sense are of interest to both science and business practices. Currently, most countries pursue policy to support innovations which are considered to be among the fundamental determinants of economic development.

Sustainable and smart growth in the economy of the European Union, including in agriculture, is to be ensured by innovativeness. The key challenge for agriculture in the future is not only how to produce more, but also how to produce better. Embracing demand driven research and innovation, as well as improved dissemination of best practices will be essential to this end (EU Commissioner for Agriculture and Rural Development).

Innovations must be construed as creating something new and improving something that already exists. The literature provides different definitions of "innovation", i.e. it may be interpreted as a process and as a result. The first who attempted to define "innovation" in relation to the economy was Schumpeter (1960). He construed it as significant changes in the production function, the essence of which is to combine factors of production differently than so far. P. Drucker (1992) treated innovations as an important tool for entrepreneurs who may use it to make their entities competitive. For research and comparative analysis purposes, it is recommended to use the OECD's definition of "innovation", i.e. implementation of a new or significantly improved product (good or service), or process, a new marketing method, or a new organizational method in business practices, workplace organization, or external relations (Podręcznik, 2005).

This paper aims at presenting innovative solutions for plant production which, if used, may enable Polish farmers to compete effectively in the global market.

INNOVATIONS IN AGRICULTURE

Innovations are essential in modern agriculture. As a matter of fact, they are a significant driver of its progress. Given the increasingly difficult, changeable environment

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and unpredictable economic conditions, agricultural producers should consider the introduction of innovative solutions as one of the opportunities for effectively improving competitive advantage in the global market. At the same time, the use of innovative solutions in agriculture should ensure the use of resources and the provision of ecosystem services in a sustainable way.

The concept of innovations in agriculture takes account of its specifics related to the seasonality of production cycles and the dependence of production and economic results on natural phenomena and uncertainty due to market disruptions. In accordance with Maziarz (1984), "agricultural innovation may be a product or technological treatment, i.e. a certain production activity or an idea, e.g. a specific economic cycle, or another value – raising the social prestige, the pursuit of teamwork by an individual". On the other hand, Ryznar (1995) defines agricultural innovations as any new ideas, concepts, thoughts to streamline production processes, treatments related to a production holding and a household as well as any machine to facilitate work or boost its effectiveness and all the products of human activity, patterns of conduct or values not found earlier in a holding or a rural area.

The ability to efficiently implement innovations in agricultural holdings and to acquire new knowledge as well as the effective use of biological progress in plant production (selection of new plant varieties resistant to diseases, pests, and adverse climatic conditions with respect to environmental, organizational or market conditions) and animal production are a challenge for modern agriculture. The sustainability of agricultural holdings in the longer term is determined by their ability to compete with other similar entities in the market. Competitive holdings are larger, invest a lot of funds, take in innovations (Józwiak et al., 2014). The need for using innovative solutions in agriculture stems not only from the opportunity for gaining competitive advantage over other market participants, but also from agricultural conditions, such as: climatic conditions, economic conditions, demand driven by consumer preferences, and the search for alternative sources of income.

Macroeconomic changes, which involve being in constant pursuit of meeting the basic needs of a growing population and, consequently, the need for feeding that population, as well as energy needs, are among the main factors behind innovative development in agriculture. On the other hand, widespread urbanization makes agricultural land less available and thus forces farmers to consider innovations as an opportunity for compensating for this trend.

Despite the changes that took place in agriculture, fragmentation is still one of its features, hence a reduction in financial resources. It is hard for a single entrepreneur to master and use all the necessary knowledge, therefore it is increasingly important to provide producers with support from specialized state and private advisors (Klepacki, 2015). As a result, agricultural producers are increasingly forced to pursue knowledge-based farming. As indicated by Heijman et al. (1997), however, such specificity makes agriculture a highly competitive sector in which production takes place in a large number of small-scale holdings which have negligible impact on the price of their products. The only way to improve the economic situation is to reduce production costs. Consequently, technological innovations, which increase production and make it possible to decrease unit costs, are adopted by farmers.

It seems that the so-called gene revolution is currently vital to further increase plant productivity. As indicated by Tuberosa et al. (2003), learning how organisms function at molecular level made it possible to analyze, understand, and manipulate the DNA of plants and animals. Modern plant varieties and animal breeds contributed the most to the fact that global food production grew faster than the population (Borlaug, 2000). In 1950–2010, primarily thanks to scientific advances, cereal production increased 3.6-fold without a significant increase in cultivation area, while the population at that time increased 3.1-fold. As a result of starting to cultivate new plant varieties, crop yields grew every year by an average of 1–3%, depending on which crop species was cultivated. Currently, the share of varietal progress in the total yield growth is 80–90%, while half a century ago, it was 45–55%. Therefore, innovative varieties become more and more important as far as increasing crop yields is considered. As biotechnology develops rapidly and increasingly sophisticated plant breeding techniques and plant production technologies emerge, this trend is expected to continue (Gacek, 2015).

Progress is not about introducing innovations of all kinds, but rather about diffusing those which bring beneficial effects to agricultural holdings in which they are applied. Progress may take the form of higher farmer income, improved production efficiency, higher competitiveness of holdings, storage of additional quantities of CO_2 in soil, etc. (Józwiak et al., 2012).

BIOLOGICAL INNOVATIONS IN AGRICULTURE

Biological innovations in agriculture involve creating crop varieties which are carriers of biological progress in plant production, i.e. which are vital to modern agriculture. They make it possible to create new plant varieties which are more fertile and of better quality. The new, improved crop varieties are what intensifies agricultural production, while progress is environmentally and ecologically friendly.

Scientists consider progress in plant production as an opportunity for developing plant cultivation and breeding methods based on information about the properties of plants and their behaviour under different cultivation and environmental conditions. They work to create innovative varieties intended for different soil and climatic conditions, various forms of farming and varieties necessary for preserving biodiversity, and protecting the environment. Introducing modern technologies in breeding, including in vitro cultures, molecular markers, genetic plant modification, micromethods for assessing the quality of plant material at early stages of breeding, allows for a shorter breeding cycle, intentional and monitored gene transfer, increased selection efficiency and, consequently, significantly lower costs of breeding new varieties (Święcicki et al., 2011).

Biological progress, whose carriers are contemporary plant varieties, ensures high yields while maintaining high quality of agricultural products. Varieties with increased resistance to biotic and abiotic stresses contribute to more accurate and more stable crop yields. It is expected that new varieties will help reduce the consumption of expensive and environmentally hazardous synthetic means of production and enable the preservation of biodiversity in agriculture, including the protection of the environment (Gacek, 2015).

In vitro cultures, which are used to shorten the breeding cycle, are among innovations in plant production. Breeding new crop varieties is time-consuming and thus shortening the breeding cycle by even several years with this method allows for reducing the production costs of new varieties. New plant species can be created by using two methods: a traditional one, i.e. by plant self-pollination, or by a direct one, i.e. by the haploidysation of hybrids of early generations. The latter allows for shortening the time of breeding of a variety by 4–6 years. One disadvantage of these methods is that their efficiency depends on a plant genotype (Ślusarkiewicz-Jarzina and Ponitka, 2003) and that the efficiency of doubling the number of chromosomes in haploids is still unsatisfactory.

Molecular methods in research on crop genomes and the so-called model species are another innovative solution which provides not only new information about genetic conditioning of the observed variability in plant utility features, but also techniques for performing plant selection based on a genotype rather than phenotypic observations. DNA markers find practical use mainly in resistance breeding and selection with respect to certain quality-related properties (Tsilo et al., 2011). Such markers allow for more effective selection of high-yield plants than is the case with selection based on field experiment results only.

Technological progress contributes to the development of genetics. Innovations are also used for genetic plant modification in agriculture. These methods are used in plant breeding to accelerate plant growth. Transformation, which allows for transferring important genes to plants, is one of them. After nearly 50 years of research, varieties attractive to both producers and consumers could be introduced to plant production. Transgenic plant cultivation is widely used in: the USA, Brazil, Argentina, India, China, where primarily soybeans, cotton, maize, oilseed rape and sugar beet are cultivated. As indicated by James (2010), the area of such crops increased significantly, i.e. from 1.7 million hectares (1996) to 148 million hectares. Nevertheless, despite the obvious advantages of these type of products, there are more and more opponents of GMOs. As no research was carried out on long-term effects of consuming these type of plants, more and more countries ban the use of genetically modified plants.

Currently, high and stable yields are guaranteed primarily by hybrid (heterosis) varieties. Plant breeding, mostly open-pollinated plant breeding, uses the phenomenon of heterosis, i.e. exuberance of the first generation of hybrids created by crossing certain inbred lines. The phenomenon of superiority of heterozygous hybrids over their initial homozygous forms occurs on a full scale, i.e. in all plants of the first generation only. In further generations, this phenomenon is "blurring", as a result of segregation, recombination and homozygosity growth, and may only occur in some individual plants. This means that the seed of hybrid varieties may not be multiplied traditionally – it may only be used once (Święcicki et al., 2011). The introduction of hybrid varieties enables farmers to increase their yields (by over a dozen percent), reduce the use of pesticides (due to their resistance to diseases and lodging as well as high adaptive resistance). As indicated by Du et al. (2010), yields of 10 hybrid varieties of wheat introduced in China are higher than those of traditional varieties by 20% on average.

INNOVATIONS IN PLANT PRODUCTION

Farming is an element of agricultural technology characterized by high time and energy consumption (Kordas, 2005). The use of innovative agricultural treatments, which are environmentally friendly or counteract the consequences of current climate change, is one way to improve yield quality and production profitability (by using the Decision Support System – DSS for precise soil and foliar nutrition of plants during the growing season, the water microretention method for irrigation as well as economical irrigation systems).

If implemented, farming simplifications have many advantages, such as: the prevention of soil erosion, the intensification of biological life in soil, higher organic matter content and soil moisture, lower fuel consumption, lower CO2 emissions and air pollution. Furthermore, they reduce energy inputs, save working time and make fertilizers and pesticides retained in topsoil. Ploughless tillage systems ensure higher energy efficiency (Małecka, 2006).

Precision agriculture is one of the most innovative forms of farming. In accordance with the MIT report (MIT, 2015), such agriculture is characterized by a number of computer technologies to support the economy of plant production. It may be an alternative to traditional agriculture, as it helps facilitate work by using computer assistance which uses data on the spatial diversification of crops within a field. Yield maps are created by using the latest technology (GPS, satellite images) and computerization which makes it possible to precisely plan fertilization and plant protection. This type of farming consists in the selective dosing of fertilizers and its adaptation to the possibility of increasing higher-quality yields. It takes knowledge of the exact cultivation area and soil fertility to use GPS technology. Accurate maps may be used when submitting applications for subsidies for farmers which is their additional advantage. Moreover, the exact knowledge of a holding allows for controlling the variability and abundance of constituents within the entire holding and detailed planning of plant varieties adapted to soil fertility. The aim of precision agriculture is rational fertilization.

As far as innovative precision farming is considered, computerized spreaders and sprayers must be used to ensure that chemical agents are dosed as required and that their doses can be changed during treatment. Variable dosage is possible when using e.g. Multi GPS-VRA (Variable Rate Application). The system consists of a field computer with GPS and software which is linked up to a spreader's computer. Combining GPS technology with accurate maps allows for spreading fertilizers in planned doses. An advantage of this technology is that the consumption of fertilizers is reduced by several dozen percent through adjusting the dosage of fertilizers to soil fertility and plant requirements. Moreover, solutions of this type make it possible to achieve more balanced yields of higher quality and, at the same time, use less chemicals which prevents over-fertilization of fields (Leń, 2012).

The main objective of balanced fertilization is not to achieve maximum yields, but rather to achieve higher income by a farmer. This implies that each increased fertilizer dosage must result in increased yields to minimize production costs and soil pollution. Maps created for fertilization purposes may also be used when planning care treatments and operating a combine harvester by using the full working width of machines and at the time of sowing (markers eliminated).

Modern technical solutions are introduced in agriculture. An example of the application of innovation is the use of drones in agriculture to provide information necessary for increasing yields. Being equipped with sensors and a thermal imaging camera, drones allow for monitoring plant temperature and humidity. Such machines may be equipped with a laser scanner which makes it possible to measure plant height on an ongoing basis. The data collected provides information about the deficiency of nutrients in plants and their reaction to drought which enables accurate fertilization planning to increase crop yields.

Manufacturers continue to introduce innovative technologies. The advantage of compound fertilizers is that crops may be supplied with well-balanced nutrients. Another innovation in relation to mineral fertilization is fertilizer conditioning, i.e. spreading substances, which slow down the release of nutrients on fertilizers. It seems that the future of fertilization should be directed towards using foliar forms through applying liquid micronutrient fertilizers. Both liquid compound fertilizers, which contain micronutrients, and single-component preparations contain micronutrients in an amount to meet the needs of a specific plant species (Hoffman and Hoffman, 2006).

N-Lock technology proposed by Dow AgroSciences (U.S.) is an example of innovative solutions in the production of nitrogen fertilizers. This technology is designed to slow down the process of nitrification, i.e. the conversion of ammoniacal nitrogen into nitric nitrogen. With the extension of the period of 8 weeks to 12 weeks, more assimilable nitrogen remains in the area of the root system. Ammoniacal nitrogen is more stable in soil than nitric nitrogen because it does not leach to groundwater due to rainfall. If used, N-Lock technology may increase the intensity of cultivation while limiting negative impact on the environment. During three years of research in the U.S., yields were increased by approx. 7% on average by reducing both nitrate leaching and nitrogen oxide emissions. Demonstration experiments in Poland confirm the effectiveness of the applied solutions as well. During research, a repetitive increase of over 650 kg per hectare on average in yields of maize grains was achieved (www.dow.com).

Preparations based on algae extracts are another example of innovations in fertilisation. Because of the properties of these marine organisms adapted to grow very intensively under extremely difficult conditions, preparations based on compounds, which are responsible for these properties, are increasingly common among farmers. Fertilizers of this type increase the efficiency of photosynthesis, regulate the collection and elimination of water from a plant, stimulate the assimilation of nutrients by roots, and regulate plant processes. More intensive growth of plants, their flowering and fruiting as well as increased resistance to damage and adverse environmental conditions are notable effects of using these fertilizers.

Research on innovative solutions in agriculture are carried out by Polish higher education institutions as well. The staff members of the Poznań University of Life Sciences developed a globally unique greenhouse construction technology. The innovativeness of the solutions applied consists in using foam-filled walls and a climate control system. With construction costs higher by no more than 20% (compared to traditional solutions), the solution proposed by Poznań scientists makes it possible to reduce both CO_2 emissions to the atmosphere by 95% and water consumption for vegetable production by 80%. Thanks to the effective thermal insulation of individual wall parts, according to the position of the sun, and the use of supplementary lighting lamps, a greenhouse does not need additional heating. At the same time, it is recommended to use a biogas plant in the system to replace any other heat sources. The use of buffer tanks to store heat to heat the greenhouse at night is another solution for reducing greenhouse operating costs when heat is not provided by the lamps.

With regard to greenhouse production, the use of LED technology (Light-Emitting Diode) as supplementary plant lighting should also be given attention. The main advantages of this type of lighting include: long life, resistance to vibration and humidity, high energy efficiency, fast response, the optimal adjustment of the colour spectrum of light, etc. If used, LEDs may reduce energy consumption by up to 50% compared to conventional technologies. Due to its flexibility in use, lighting based on this technology may be used as top lighting and supplementary lighting of the space between plant rows. This solution allows for achieving maximum plant productivity and 15–30% higher production, depending on whether a one- or two-level system is used. Innovative supplementary lighting solutions for greenhouse crops make it possible to adjust light intensity to climatic conditions and plant requirements at different plant growth phases or cultivation density.

Land is seen as the key factor of production in agriculture. Nevertheless, land resources available for agriculture shrink due to urbanization processes. By 2050, nearly 80% of the world's population will live in urban areas (www.un.org). A way out of the problem may be innovative solutions which involve the use of vertical farming methods and, at the same time, advanced technologies of: hydroponic cultivation, organoponic cultivation without the need for covering large surface areas (Marulanda et al., 2003). Such buildings may be constructed in urban areas. Closed structures allow for making production no longer dependent on weather and climatic conditions.

There have already been a few companies in the world which took up the challenge of designing and constructing a large-scale, high-altitude vertical farm. The innovativeness of these projects consists in, inter alia, an attempt to create model solutions of autonomic farms that are integrated with the city structure, which can be used in various locations after being appropriately adapted.

A cannery in Chicago (USA), which was transformed into an ecological and self-sufficient facility in 2010, is the first implemented example of the adaptation of a brownfield building to a vertical farm. The changes gave rise to an experimental hydroponic vertical farm. Mushrooms and vegetables were first cultivated, then tilapia started to be bred in environmentally-friendly ponds. The planned completion of work is scheduled for 2016. After that, the farm will reach its maximum production capacity. The energetically self-sufficient building is based on a combined heat and power system: energy comes from methane which is produced on-site by the anaerobic digestion process (www.un.org).

Another solution involves constructing minifarms on the roofs of buildings. An example of this is the LUFA Farms project which was completed in 2011 in Montreal (Canada) and involved the adaptation of the 2900 m2 roof of a brownfield building to a greenhouse in which the hydroponic cultivation of vegetables for 1000 local residents is carried out. The greenhouse is ventilated in a natural way, while its heating system allows for adjusting temperature by zone for different types of crops.

Spread (Japan) proposed to modify vertical farm solutions. It designed a fully automated factory in which workers are to be replaced by robots. A factory of this kind, i.e. Vegetable Factory, producing 30 000 lettuce heads per day, is expected to be opened by 2017. The elimination of workers and replacing them with robots will eventually reduce costs of production by 50%, energy consumption by 30% and, if the production system will be further improved, water consumption is expected to decrease by 98%.

At the current stage of technological development, the vertical farm designs have an experimental character and they require implementation for purposes of further research. However, the contemporary model designs of farms indicates that their character is universal and, after appropriate modifications, they can be used in various climatic environments. In temperate climate zones, a greenhouse vertical farm, which is autonomous with regards to energy and water demand, will be a dominant model (Wowrzeczka, 2014). The construction of vertical farms in the vicinity of urban areas may be an antidote to food problems, climate change, and it will provide an opportunity for ensuring conditions to achieve ecological sustainability in the revitalized urbanized environment.

Water scarcity, defined in terms of access to water, is a critical constraint to agriculture in many areas of the world. In recent decades, many European countries have faced drought of different intensity. A significant part of EU river basins is water-scarce (www.europarl.europa.eu). One solution to the problem of drinking water availability is to use salt water. Desalination has already been possible for a long time, but it requires significant investments. The researchers of the Massachusetts Institute of Technology developed a system for converting seawater into drinking water by using solar energy. The Jain Irrigation System technology is so effective in removing salt and disinfecting water that it is not only suitable for field irrigation, but even for drinking. It appears that such solutions may be the future after reducing their application costs.

SUMMARY AND CONCLUSIONS

Over time, the introduction of innovations in agriculture becomes not only a possibility but also, more frequently, a necessity. Modern technologies allow for both creating competitive advantage and adjusting agricultural holdings to rapidly changing business conditions. With regard to the introduction of innovations in agriculture, one should take into account the specific features of this sector of the economy, primarily the biological and spatial character of production. Opportunities for both improving competitiveness and development of agriculture should be sought in: innovations, biological, mechanization, chemization, technological, and organizational progress.

Innovative technologies in agricultural production may reduce the negative impact of climate change. They also allow for meeting the expectations of consumers who want agricultural producers to produce organic food. The reduced use of chemicals in agriculture may only be compensated by introducing new, resistant species, and new cultivation technologies.

The fragmentation of Polish agriculture is one of the main barriers to the introduction of innovations, as small-scale holdings do not have sufficient financial resources. Farmers recognize the need for using innovative solutions in agriculture not only to meet challenges, but also to increase the competitiveness of the Polish agricultural sector. Rapid changes in the environment make it necessary to adapt both agricultural advisory services and agricultural holdings to the current challenges.

Product innovations offer the greatest opportunities for developing Polish agriculture and improving its competitiveness. Given the relatively high labour force in Polish agriculture, this may involve the development of labour-intensive activity, both agricultural and related to services based on agricultural holdings' resources.

Procedural innovations are still promising. For over the last dozen years, there have been clear processes of production concentration in agriculture which creates conditions for the implementation of modern production technologies. The larger the area of holdings, the easier the introduction of new solutions due to both higher financial resources and higher returns to scale (economies of scale).

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INNOWACJE W PRODUKCJI ROŚLINNEJ JAKO SZANSA DLA POLSKIEGO ROLNICTWA

Streszczenie. Wyzwaniem we współczesnym rolnictwie jest umiejętność sprawnego wdrażania innowacji w gospodarstwach rolnych i pozyskiwania nowej wiedzy oraz efektywne korzystanie z osiągnięć postępu biologicznego w produkcji roślinnej. Procesy globalizacyjne są katalizatorem transferu innowacji i upowszechniania postępu technicznego, biologicznego oraz organizacyjnego. Umiejętność wykorzystania innowacji w polskim rolnictwie będzie decydowała o jego szansach rozwojowych i pozycji konkurencyjnej na arenie międzynarodowej.

Słowa kluczowe: innowacje w rolnictwie, innowacje biologiczne, postęp, konkurencyjność

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