MINIMISING RISK WITH IOT AND BIG DATA TECHNOLOGIES – AN AGROECONOMIC EXAMPLE

Gábor Élő – Péter Szármes

Agricultural production is without doubt a risky business for a number of reasons. Production risk arises from fluctuations in crop yield caused, for example, by weather conditions, pests or plant diseases. Modern technologies that are also increasingly widespread in agriculture present new opportunities to improve production efficiency and mitigate risks. Precision farming using on-farm tools (through collecting information related to factors that affect agricultural activity, and planning targeted interventions based on precise information) aims to mitigate risks. Data is collected mainly by various sensors, which continuously provide data on selected soil, meteorological and other features. In this way, sensors and IT tools are helping to make better and faster decisions, and to boost the efficiency of agricultural activities. The mitigation of risks and higher yields paired with lower costs improve the profitability of agriculture.

JEL codes: Q1, O3, C6, C8

Keywords: precision farming, agricultural risks, sensor networks

1. RISKS IN AGRICULTURE

Agriculture is a key sector of the economy, even in developed countries. Agricultural production always bears a high degree of uncertainty. Yield can fluctuate significantly depending on weather conditions, pests, irrigation and fertilisation, but market and political factors also greatly influence the profitability of farming. Numerous methods have been developed for managing and reducing these uncertainties.

The framework recommended for member states in the World Bank's guidelines (Agricultural Risk Management Framework) comprises the elements shown in *Table 1.* (World Bank, 2011):

Table 1
Risk management frameworks in agriculture

Risks Assessment and Prioritization:

1. Production Risks
2. Market Risks
3. Enabling Environment Risk

Stakeholders' Assessment:

1. Commercial sector stakeholders (Meso)
2. Public sector (Macro)

Risk Management Strategies:

1. Mitigation
2. Transfer
3. Coping

Implementation Instruments:

1. Agricultural Investments
2. Technical Assistance
3. Policy support

Development Outcome

Source: World Bank (2011)

When assessing risks and establishing the order of priorities, the World Bank essentially recommends examining three large risk factor groups: the impacts of production, market and regulatory environment. It also recommends examining stakeholders at three levels: i.e. at the level of producers, of business and trading partners (wholesalers and retailers, agents, financial institutions, transporters, service providers etc.), and of public organisations, background institutions, state agencies, governments.

This study also divides the risk management strategies into three groups. The first group consists of measures for the mitigation and alleviation of risks through intervention relating to probabilities or to the damaging impacts themselves (such as irrigation, the use of resilient seeds, the early recognition of flawed development, use of the best agricultural practices). The next group comprises the transfer and sharing of risk and implied costs. Insurance policies and the hedge transactions performed in the commodities market are widely used risk transfer measures. The third group encompasses means of coping with and accepting risk; for this, the capabilities necessary for managing unexpected loss events need to be established.

The World Bank determines possible strategic directions for agricultural risk management in two dimensions (*Table 2*). One of the dimensions is articulated in terms of whether the strategic options relate to preventive, ex-ante measures or ex-post measures, while the other dimension provides a formal-informal dichotomy, further subdividing the formal mechanisms into market-based and publicly provided solutions (World Bank, 2005).

2. Table
Risk management strategies

		Informal mechanisms	Formal mechanisms	
			Market	State
Ex-ante strategies	On-farm measures	avoiding exposure to risks crop diversification plot diversification diversification of income sources buffer stock accumulation of crops and liquid assets adoption of advanced cropping procedures (fertilisation, irrigation, crop protection)		agricultural extension coordinated pest management systems infrastructure (roads, dams, irrigation systems)
	Sharing risk with others	crop sharing risk pool	contract marketing futures contracts insurance	
Ex-post strategies	Coping with shocks	sale of assets reallocation of labour mutual aid	credit	social assistance state funds

Source: World Bank (2005)

2. PRODUCTION RISKS AND PRECISION FARMING

Production risks relate to risks and uncertainties in the growth and development processes of crop production, horticulture and livestock breeding sectors. Various production factors (e.g. precipitation, drought, diseases, etc.) can influence the quantity and quality of crops and products (*Székely–Pálinkás*, 2008).
With the help of precision farming made possible by modern technology, many production factors can be precisely tracked, thereby allowing for risk reductions. Precision agriculture is referred to by various names, such as: *site-specific crop management, precision farming, site-specific production, site-specific technology, spatial variable technology*[1] (*Szármes*, 2014).
According to *Győrffy* (2002) *"precision agriculture encompasses farming that adapts to the production site, the use of varying technology within the same field, integrated crop protection, state-of-the-art technology, remote sensing, spatial informatics, geostatistics, changes in the mechanisation of crop production, and the incorporation of information technology advances into crop production. It also covers, in addition to the soil maps, the creation of crop maps and crop modelling, the comparison of soil maps with crop maps, and means of taking into account the immutable principles governing the distribution of pests, weeds and diseases within the field."*
Virtually of the literature shows *Table 3* for the presentation of the main features of conventional and precision farming:

---

[1] These all express the concept of crop management where the method of farming varies at the level of field and location. The terms spatial decision supporting system, satellite farming, computer-aided farming, spatial prescriptive farming, high-tech farming, and high-tech sustainable agriculture, provide an even clearer reference to the use of modern IT tools and continuous and location-dependent solutions.

Table 3
Comparison of conventional and precision agriculture

Conventional agriculture	Precision agriculture
Management and organisational unit: the field, which is accepted as having homogeneous characteristics as a production site	Management and organisational unit: the production site, which is accepted as varying from point to point, and heterogeneous at field level
Average sampling-based nutrient management	Nutrient management based on satellite positioning and pointwise sampling
Averaged crop protection damage assessment and intervention	Crop protection intervention based on satellite positioning and pointwise crop condition assessment
Same plant density and variety	Species and variety-specific seeding
Same machine operation	Machine operation varies by production sites
Unified crop in space and time at field level	Unified crop in space and time organised into homogeneous blocks at production site level
Few decision alternatives	Many decision alternatives

Source: Tamás (2001)

Swinton és *Lowenberg-DeBoer* consider precision crop production systems to be those that use GPS[2], GIS[3] and VRT[4] technologies. The combined use of these reduces the risk of agricultural production. The higher quantity and improved accuracy of the information increases the controllability of crop production processes, as well as the effectiveness with that production inputs can be utilised (Swinton–Lowenberg-DeBoer, 2001).

Precision farming, therefore, means farming that adapts to local conditions and needs, even within a field. An integral part of this is precise measurement and precisely regulated intervention (Lowenberg-DeBoer, 1999). This is why sensors are important elements of precision farming, and are used to continuously measure various soil and environmental characteristics, and parameters related to agricultural operations (e.g. during the harvest). Using the data makes

---

[2] GPS: Global Positioning System
[3] GIS: Geographic Information Systems
[4] VRT: Variable Rate Technologies

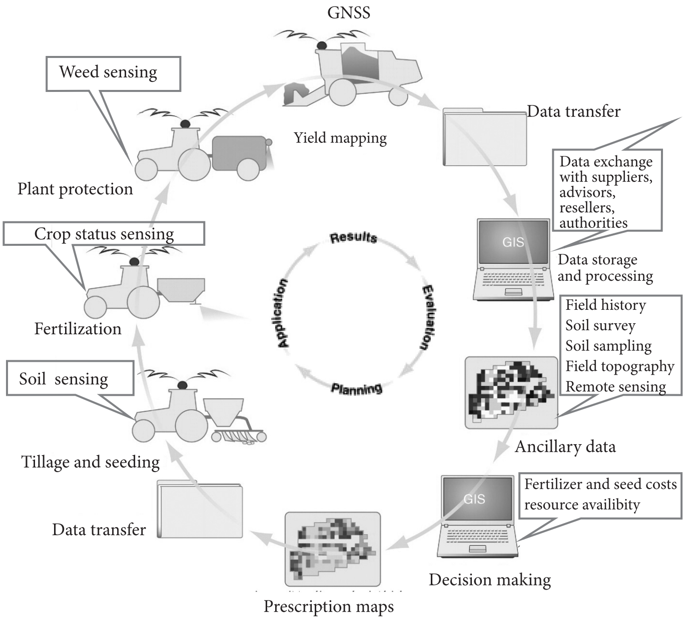
it possible to intervene more quickly and effectively, and in this way negative outcomes can be more easily avoided and costs can be reduced.

According to certain experts, because of its comprehensive systemic approach, precision crop production can no longer be regarded as simply a new crop production method, but essentially as a new production system. One of the main objectives is to reduce the weight of uncertainty variables during decision-making about crop production, by having better and more accurate information available and responding at a higher level to factors that cannot be influenced (*Whelan–McBrateny*, 2000; *Dobermann* et al., 2004).

The process of precision farming is summarised clearly in *Figure 1*.

1. Figure

The information process of precision farming



Source: Gebbers– Adamchuk, 2010

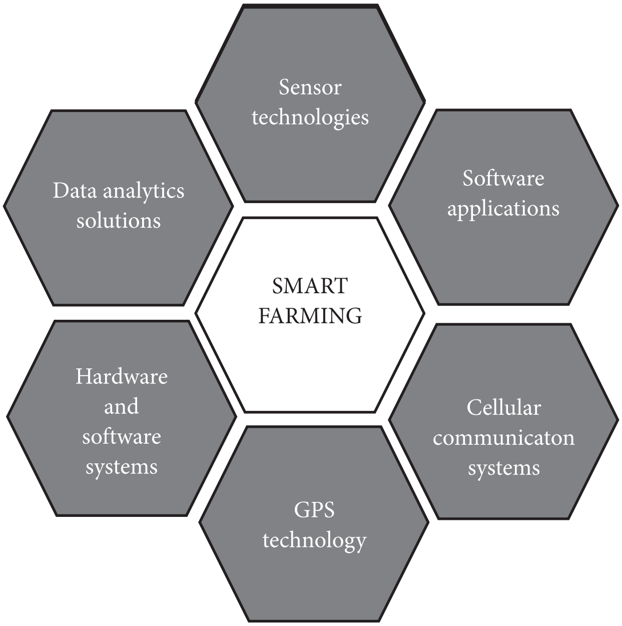
3. INTERNET OF THINGS, SENSORS AND BIG DATA IN AGRICULTURE

The "Internet of Things (IoT) refers to a system of embedded devices, linked together in a network, each with their own unique ID. In this way, various appliances, systems and services can be connected together without human intervention. This facilitates data collection and automation of processes in numerous areas of application. As a result, much more data can be processed, more rapidly, which in turn induces a further increase in data quantity (*Ashton*, 2009).

Sensors are important elements of precision farming, and are used to continuously measure various soil and environmental characteristics, and parameters related to agricultural operations (e.g. during the harvest). Precision farming represents an on-farm risk management strategy, and can be used primarily to reduce production risk, although optimised irrigation, fertiliser and pesticide use typically leads to a reduction in costs related to these, which in turn also reduces the risk arising from price fluctuations to a certain extent.

Based on expert opinions (*Lencsés*, 2013), above a certain farm size using one or more elements of precision agriculture technology is clearly profitable. This is the reason why IoT is spreading fast in agriculture. According to a study by Beecham Research (Beecham Research, 2014), population growth will lead to a substantial increase in demand for food in the future, and agricultural applications of IoT could play a key role in increasing production in line with this demand. *Figure 2* shows the elements of smart farming. It clearly illustrates the importance of the role played by IT and telecommunications technology in the agriculture of the future.

2. Figure
Elements of smart farming



Source: Beecham Research (2014)

The adoption of modern technology in agriculture is motivated and hindered by numerous business and technology drivers and barriers. *Table 4* summarises the most important factors determining developments in this area. Based on the assessment of these factors, Beecham Research's study concludes that modern technologies will play a more and more important role in agriculture (Beecham Research, 2014).

4. Table
Drivers and barriers to the adoption of modern technologies in agriculture

Business and market drivers	Technology drivers
Increasingly urgent need to reduce waste and increase efficiency	M2M technology is being adopted in a growing number of industries
Soil erosion from intensive farming needs to be reduced	Prices of sensors and connectivity are decreasing
State aid and funding is available for new tools	Big data is capable of handling the tidal wave of sensor data
The impacts of climate change and environmental pollution need to be offset	Farmers are becoming more proficient at using IT devices
Return on investment is difficult to prove	Network coverage is often inadequate out in agricultural fields
Shortage of new entrants in the agricultural sector	Standards for sensor systems are still under development
Industry risk is substantial (weather, political factors)	There is no well-established agricultural management software
Ownership of gathered data remains an unresolved issue	Uncertainty regarding the management and protection of data

Source: Beecham Research (2014)

With the help of precise GPS systems, work in the fields (ploughing, seeding, etc.) can be performed more cost-effectively. In the future, self-driving tractors and combine harvesters could become widespread. If the area of a field remains unchanged, then GPS data recorded during work performed in the previous year can be used to guide an agricultural vehicle in the next. A given agricultural task can be optimised on the basis of the positioning, speed and consumption data of the various vehicles. Automated control and communication between units could make the use of vehicle fleets more efficient: during a harvest, for example, the movement of the combine harvester and the trucks transporting the harvested crop can be coordinated (*Scroxton*, 2016).

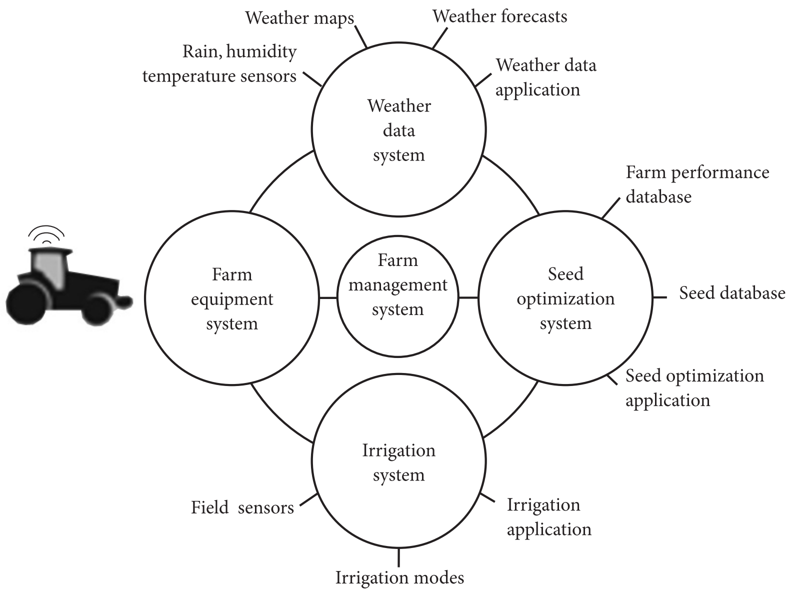
The IoT can also be used to optimise fertilisation and irrigation. Senors can be used to measure the soil’s nitrogen, phosphorus and potassium levels, and it is possible to determine how much fertilisation is necessary in individual patches for growing a given plant. The IoT can also be used for the optimisation of crop spraying: in more highly infected areas more chemical can be used, at the same time spraying can be shut down near protected watercourses (*Scroxton*, 2016).

The IoT has the potential to bring about revolutionary changes in agriculture. The article by Michael E. Porter and James E. Heppelmann (*Porter–Heppelmann*, 2014) gives a clear explanation of the essence of these changes. Smart, networked products have their own computing capacity, and are connected to some kind of network. They have hardware, software and network elements. Smart products not only have the potential to transform competition within an industry, but can also alter the structure of that industry. Boundaries of the industry can expand to encompass other, related products, so that together they are capable of satisfying a more comprehensive range of needs.

Instead of the functionality of individual products the basis for competition shifts to the performance of broader product systems, where a given product manufactured by a company is only one element. The manufacturing company may offer a complex bundle of interrelated equipment and services, which optimise the end result for the customer. In this way an industry such as tractor manufacturing could expand and become an industry of agricultural production system (*Porter–Heppelmann,* 2014).

The process often goes even further than this; beyond a product systems the industry extends to system of systems as well. These are coordinated and optimised clusters of various product systems and interdependent external information. A good example of this is a smart building, a smart house or a smart city. John Deere and AGCO now link not only agricultural machines, but also irrigation sensors, soil sensors and information about weather, current and future grain prices, so that farmers could optimise the overall performance of a given agricultural facility (*Porter–Heppelmann*, 2014).

3. Figure
The transformation of industry boundaries: system of systems



Source: Porter–Heppelmann (2014)

In order to harmonise related systems, a large quantity of information needs to be managed, stored and processed. The use of Big Data technology and methods is essential in achieving this. John Deere gathers data about equipment and sensors, weather, soil and markets, links them and makes them available to agricultural producers via various different platforms. With the help of this information farmers can determine what crops to sow, when and where to plough, what route to take, and when and where it is worth selling the crop. Efficiency improves, risks can be reduced, and ultimately quantity of the yield and income increase (*von Rijmenam*, 2016).

John Deere's FarmSight system helps to boost productivity in three ways (*von Rijmenam*, 2016):

1. The equipment optimisation element monitors the operation of machines and equipment, determines when there is a need to replace or repair components, thereby reducing downtime due to malfunctions.
2. The production logistics element assists farmers in monitoring the vehicle fleet, remotely accessing information related to equipment, and implements data interchange between machines.

3. The decision support system helps farmers to have more information, to make better decisions, to prevent errors and as a result to increase efficiency and profit. Farmers can access past and current field information, assess soil samples, and share these data items.

4. SENSOR TECHNOLOGY IN THE AGRODAT PROJECT

The Agrodat project, an R&D project of well-known industrial and scientific partners, set out to build a major agricultural information system on a countrywide scale in Hungary. The project's IT developments tie in closely with the specific characteristics of agricultural production and the efforts to expand the boundaries of agricultural knowledge, with the ultimate goal of increasing efficiency and effectiveness in agricultural production.

Agricultural information systems shall be able to make recommendations about production steps and forecasts about weather and environmental conditions, crop yields, etc. Value-added services are built on comprehensive data, collected mainly by sensors and processed by an IT infrastructure. The Agrodat project aims to widen its sensor network for the whole country and create an infrastructure to be able to handle the appropriate data volume.

In order to make good decisions in the course of crop production activities, we need to collect information on field-patch level about:

- soil properties (e.g. humus content, water content, micro- and macroelements, etc.);
- meteorological data;
- needs and nutrient requirements of the produced crop;
- weed and pest population;
- quantity and quality of harvested crop.

In the Agrodat project we considered the use of sensors for measuring the following factors:

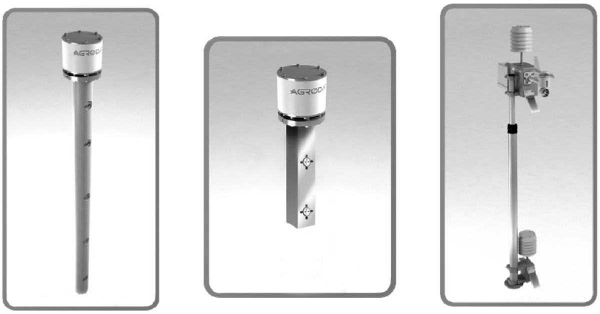
- air movement (wind speed, wind direction, air pressure),
- precipitation (quantity and intensity),
- air temperature,
- oxygen and carbon dioxide concentration,
- water vapor content,
- solar radiation (intensity and duration),
- leaf wetness,
- soil moisture, ground water level,
- soil temperature,
- soil salt content, soil conductivity.

For the information system, a large volume and variety of field data shall be collected about crops and environmental conditions (soil moisture, soil temperature, air temperature, precipitation, solar radiation, etc.). Sensor networks can provide most of the data. Soil sensors can measure the soil's dielectric permittivity, electrical conductivity, soil temperature. These measurements can help to make inferences about the soil's water and salt content, which – especially in drier areas – can substantially influence the growth of crops. These data can be used for irrigation planning, forecasting plant diseases, and measuring soil respiration. By measuring the soil's water potential, inferences can be drawn regarding the quantity of water that can be taken up by the plants. A water sensor can measure the level of groundwater, and help to monitor the soil's water balance (Szármes–Élő, 2014).

Light sensors can measure the intensity of photo-synthetically active radiation. A special sensor can measure the spectrum of reflected light in certain wavelength bands, in order to determine NDVI (Normalized Difference Vegetation Index) and PRI (Photochemical Reflectance Index) values. These correlate closely with photosynthetic activity, growth of plant vegetation (leaf area index) and biomass volume. Spectral data analysis can also help to monitor plant health (Szármes–Élő, 2014).

Sensors can measure relative humidity, air temperature and vapor pressure. Precipitation sensor provides information about the quantity of precipitation, which is a key factor determining the water balance of the area. Wind sensor measures the direction and speed of wind; this is an important meteorological factor, and could be important, for example, when predicting the spread of airborne pathogens. *Figure 4* shows a few of the sensors developed in the Agrodat project.

4. Figure
Agrodat agricultural sensors



Source: www.agrodat.hu

Leaf wetness sensor measures the spacial and temporal extent of wetness on leaf surface, and detects ice formation. This sensor is made of thin (0.65 mm) glass wool, which has similar evaporation properties as a healthy leaf, so condensation and evaporation is of similar extent as those of a normal leaf. Its data is useful for forecasting plant diseases (Szármes–Élő, 2014).

In the Agrodat project, image sensing and image processing technology is also being developed that can be used to recognise rodents that cause damage to plants, and generate an automatic alert (*Paller*–Élő, 2016a). This sensor system can be developed further in future, for example for the recognition of harmful inspects in an insect trap. For image sensors, a substantially larger quantity of data needs to be processed and transmitted. The higher computing capacity and larger data volume transmitted require more energy, which for a device located in the field is only available in a limited extent. For this reason, energy consumption is a key consideration when designing such sensor systems (*Paller*–Élő, 2016b).

5. RISK MANAGEMENT OPPORTUNITIES USING PRECISION FARMING

In order to implement precision agriculture the following steps need to be taken (*Grisso* et al., 2009):

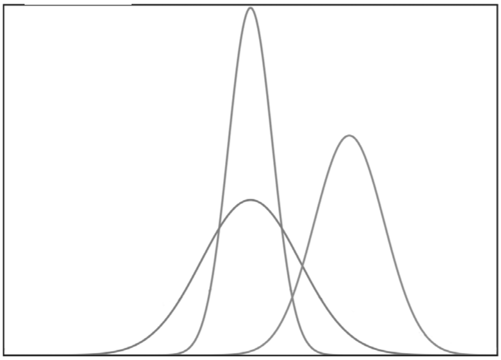
- Review of current information: soil analysis maps, harmful organism and pest maps, overview of precipitation data, earlier crop production information,
- Collecting data: determine yield variability,
- Assessment of results,
- Data evaluation: make decisions, create maps, action plans,
- Development of strategy and management plans.

The most important benefits of precision agriculture are the following (*Reisinger–Schmidt*, 2012):

- yield improvement (in quantity and quality);
- more accurate and cost-effective seeding (reduced seed use);
- reduced pesticide use and irrigation water consumption (through area optimisation), lower costs and a smaller environmental burden;
- improvement in profitability;
- improvement in the quality of work performed;
- better ability to monitor production.

With the use of precision farming, the curve of the density function showing the probability distribution of crop yield can be narrowed and shifted in the direction of higher values, as shown in the following schematic diagram.

5. Figure
Change in the probability distribution of the crop yield



Source: diagram by author

Table 5 summarises the various risks that are present in agriculture.

5. Table
Risk factors in agriculture

Production technology risk factors	Crop rotation risk
	Soil preparation risk
	Seeding risk
	Plant care
	Harvesting risk
	Storage risk
Weather risk factors	Temperature
	Precipitation
	Light
	Air movement
Risk factors associated with natural disasters	Excess surface water, flood fire, etc.
Geographical location and soil requirements	Climatic change, soil quality deterioration

Pests and diseases	Harmful insects, fungal infections, etc.
Environmental risks	Air and water pollution, etc.
Vandalism and other damage	
Political risks	
Administrative risks	
Economic policy risks	
Market risks	
Economic and financial risks	
Infrastructural risk factors	
Information, marketing, reputation risks	

Source: Élő et al. (2015)

In the following we demonstrate an extremely simplified risk calculation that illustrates the potential impacts of using precision agriculture. The methodology is based on several preceding works (*Kovács–Koppány*, 2014; Élő et al., 2015). Calculations are based on assumptions and expert estimates. As research progresses, hard measurement data will become available with respect to the risks influenced by precision farming.

The presentation of this analysis illustrates how to conduct risk calculations, and we made numerous simplifying assumptions. We have intentionally configured risk factor groups to ensure that they can be treated as independent of each other. Analysing risks that are not interconnected is always far simpler than analysing interdependent risks. Based on empirical data, isolating even the impacts of consolidated risk factor groups is very difficult. The difficulties involved in quantification and the shortage of data have led us to use estimates from industry experts, and we have attempted to elaborate and apply techniques that are capable of generating risk distributions from relatively little information.

It is for precisely this reason that our calculations relying on expert opinions are based on triangular distributions, which is exceptionally widely used in business simulation and project management practice. Triangular distribution can be defined with three parameters: the most probable (most common), the lowest possible, and the highest possible values. In response to the various risk factors the actual data may differ favourably or unfavourably from the target figures. We set the maximum positive and negative percentage differences; in other words, the lower and upper limits of the interpretable range of a triangular distribution; on the basis of expert opinions (Élő et al, 2015).

For agricultural activites we defined five factor groups. For the sake of simplicity, with respect to farms engaged in crop production, we only deal with the growing season. We assume that the crop yield that is consistent with the characteristics of the given area of land, is known. In our analysis we treat the average annual yield as a reference value, and our experts give the scope of percentage differences from this.

We have individual risk factor groups evaluated individually. We ask our expert, for example: how much of a maximum positive and negative difference divergence from the reference yield do you think could result as the impact of political, regulatory and administrative factors (POLREG)? Our expert replies that these could cause a difference of up to ten percent in a positive or negative direction. We have the impact of market (MARKET), environmental (ENVIR), professional, technological, personnel (PROTEC), and other special factors on which precision farming (PRECI) has an effect evaluated in the same way. The expert assumptions are shown in *Figure 6*.

Figure 6 also shows the triangular distributions associated with expert opinions. The highest value of each density function is at the zero-percent difference; in other words, at the reference yield. The positive and negative differences are attributable to various risk factors. Certain factors (under current settings) may only cause small differences, while others (such as environmental factors) can cause substantial differences.

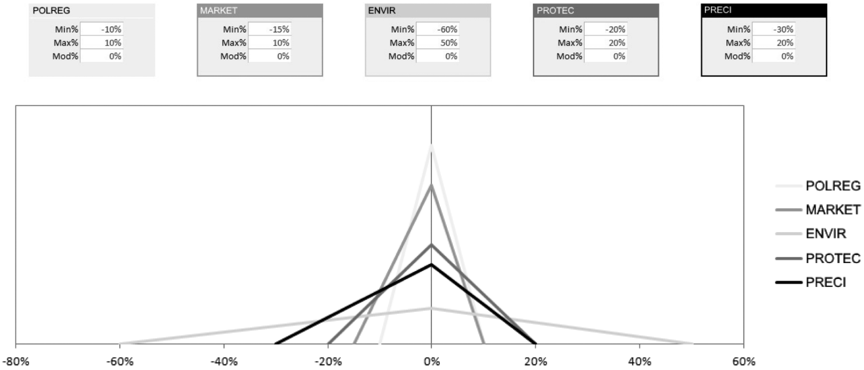
When aggregating risk factors we took into account the importance weights of factor groups as assessed in the growing season.

For rating the risks, we used a four-point scale:

- 0 = negligible/disregarded/not important
- 1 = low/less important
- 2 = medium/important
- 3 = high/critical

In order to ensure progressivity, the numbers 0, 1, 2 and 3 are the powers of the base for the natural logarithm (e); in other words, in the weighing process we create exponential differences. This represents an approximately three-times difference in terms of effect between 1 and 2 and 2 and 3.

6. Figure
Impacts of the risk factor groups based on the expert assumption: positive and negative differences from the reference yield



	POLREG	MARKET	ENVIR	PROTEC	PRECI
Min%	-10%	-15%	-60%	-20%	-30%
Max%	10%	10%	50%	20%	20%
Mod%	0%	0%	0%	0%	0%

Source: Élő et al. (2015)

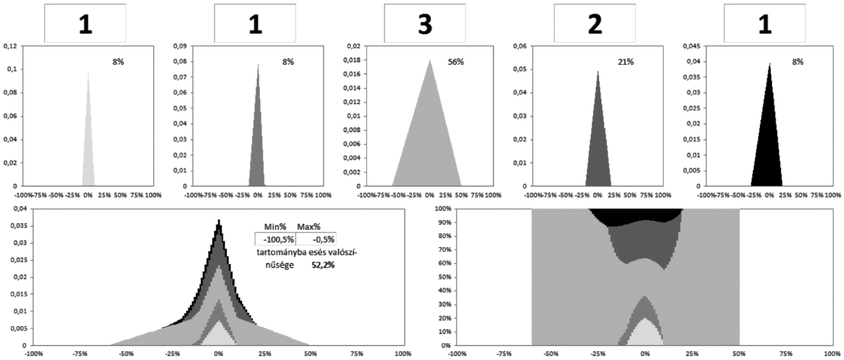
We attempt to define the aggregated distribution, which expresses the combined effect of all factors by overlaying, that is ‘superpositioning’, the distributions. The essence of the procedure is easiest to explain if we take a risk-free situation as our starting point. The appropriate settings for this can be generated in two ways: one is to set the percentage differences for every risk factor group to zero; the other is to set all importance weights as zero. In this case, the probability distribution diagram is represented by a vertical line of one unit in height, drawn to 0%, denoting that, to one unit of probability, no difference from the reference yield can be expected. In this case, therefore, there is no risk whatsoever.

Obviously, the risk-free situation is only a theoretical scenario that does not occur in reality. But taking it as the starting point makes easy to see that if a risk emerges at a factor group; that is, if the possibility of a positive and/or negative difference arises, then the vertical line drawn at 0% will decrease in height. The question is: by what extent? What proportion of the unit of probability centered on 0% should we distribute according to the triangular distribution associated with the given risk factor group, in the specified range of negative and positive divergences?

This is where the importance weights come into play. By using the importance weights, we effectively specify the share that the given risk factor group represents within the unit of probability. We take the sum of the values of the weights set for each of the risk factor groups using the natural base exponential function, and divide the exponential weight of the given factor with this.

The assumed values of importance weights, as well as the minimum and maximum divergence values set by experts can be seen in the top row of Figure 7.

7. Figure
Aggregation of triangular distributions



Source: Élő et al. (2015)

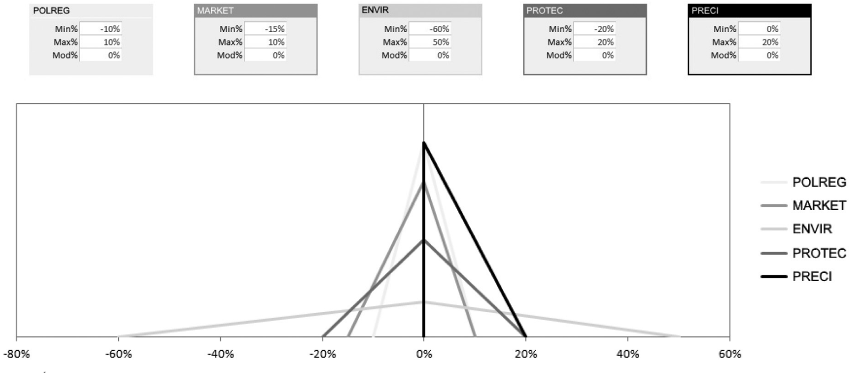
The more risk is associated to different factors, the more the unit of probability will be distributed in accordance with the settings, and the lower the probability of a 0% difference will be. If we take all five distributions into account and overlay them in accordance with the rules described above, we get the density function profile displayed in the bottom left corner of Figure 7. The diagram at the bottom right corner aggregates risk to 100% and thus shows the ratio in which differences of a given extent can be attributed to our 5 risk factor groups.

Given the above risk settings, the probability of negative differences from the planned yield (losses) is 52.2%.

Now we shall see, using this simple example, what is the impact of using precision agriculture technology on risks related to the crop yield.

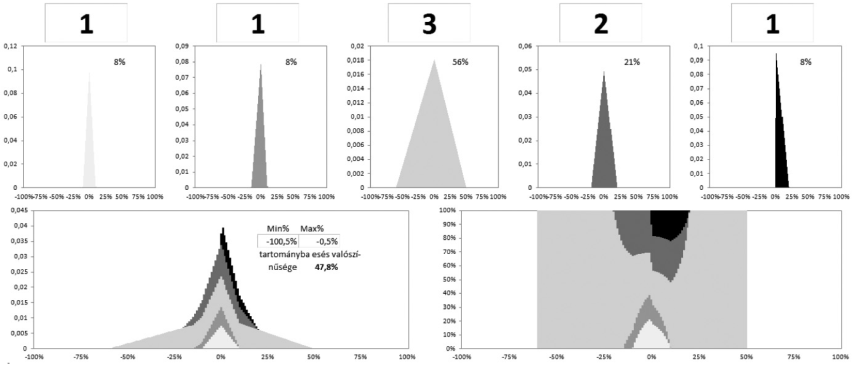
The precision agriculture tools make it possible to avoid some threats carried by risk factors classified into the fifth factor group, because they warn us to take necessary countermeasures in good time. Or to put it another way, this triangular distribution will not have a negative range, as the lowest possible value matches the most probable reference yield; i.e. the Min% value of the PRECI factor group is zero (see *Figure 8*).

8. Figure
The impact of using precision technology (1)



Source: Élő et al. (2015)

9. Figure
The impact of using precision technology (2)



Source: Élő et al. (2015)

As a result of these risk factors, the density function profile changes as shown in the bottom left part of Figure 9, and consequently the probability of negative differences from the planned value decreases from 52.2% to 47.8%. We can interpret the 4.4 percentage point reduction in the probability of losses as the impact of using precision agriculture.

6. SUMMARY

Diverse risks are associated with agricultural production. Managing these risks several methods shall be used. Beside risk sharing strategies (e.g. business insurance policies or the National Agricultural Damage Mitigation System) on-farm tools and techniques are play an increasingly important role. Precision farming incorporates an array of modern technological devices into farming in an integrated manner with the goal of optimising production processes and reducing the influence of risk factors. The continuous monitoring of environmental conditions and the crop status makes it possible to intervene in a timely and targeted fashion, which increases the expected quantity of crop yield; meanwhile, the optimised irrigation water consumption, fertilisation use and crop protection facilitates a reduction in expenditures and costs. These helps to reduce the environmental burden of agriculture and to improve the profitability of farming. This is an important step towards achieving sustainable agriculture, which is hugely important given the rate of growth in the global population.

REFERENCES

Ashton, K. (2009): That 'Internet of Things' Thing. *RFID Journal*, http://www.rfidjournal.com/articles/view?4986 (downloaded: 29.04.2014)

Beecham Research (2014): Towards Smart Farming. Research report, https://www.beechamresearch.com/files/BRL%20Smart%20Farming%20Executive%20Summary.pdf (downloaded: 05.10.2016)

Dobermann, A. – Blackmore, S. – Cook, S. E. – Adamchuk, V. I. (2004): Precision farming challenges and future directions, pp. 1–19. http://www.regional.org.au/au/pdf/asa/2004/127_dobermanna.pdf.

Élő, Gábor – Koppány, Krisztián – Kovács, Norbert – Szabó, József – Szármes, Péter (2015): *Precíziós gazdálkodás: Kockázatmenedzsment* [Precision Farming: Risk Management]. Győr: Universitas-Győr Nonprofit Kft., p. 106 (ISBN:978-615-5298-52-3).

Gebbers, R. – Adamchuk, V. I. (2010): Precision Agriculture and Food Security. *Science Magazine*, 12 February, Vol. 327, No. 5967, pp. 828–831.

Grisso, B. – Alley, M. – McClellan, P. – Brann, D. – Donolue, S. (2009): *Precision farming: a comprehensive approach.* Virginia Polytechnic Institute and State University, pp. 1-6., http://pub.ext.vt.edu/442/442-500/442-500.html.

Győrffy, Béla (2002): A biogazdálkodástól a precíziós mezőgazdaságig [From Organic Farming to Precision Agriculture]. *Agrártudományi Közlemények* (*Acta Agraria Debreceniensis*), Vol. 2. issue 9., pp. 81–86.

Kovács, Norbert – Koppány, Krisztián (2014): Kockázatelméleti és módszertani építőkockák [Building Blocks of Risk Theory and Methodology], in: Kovács Norbert (ed.): *Építőkockák*. Győr: Universitas-Győr Nonprofit Kft.

Lencsés, Enikő (2013): *A precíziós (helyspecifikus) növénytermelés gazdasági értékelése* [The Economic Evaluation of Precision (Site-Specific) Crop Production]. Doctoral thesis. Gödöllő: Szent István University, Doctoral School of Business and Management.

Lowenberg-DeBoer, J. (1999): Risk management potential of precision farming technologies. *Journal of Agricultural and Applied Economics*, Vol. 32. No. 2., pp. 275–285.

von Rijmenam, M. (2016): John Deere Is Revolutionizing Farming With Big Data. Research Article, *Datafloq*, 21February, https://datafloq.com/read/john-deere-revolutionizing-farming-big-data/511 (downloaded: 10.10.2016).

Paller, Gábor – Élő, Gábor (2016a): Energy-efficient Operation of GSM-connected Infrared Rodent Sensor. SENSORNETS 2016, 5th International Conference on Sensor Networks, Rome, Italy, Volume: Proceedings of the 5th International Conference on Sensor Networks, pp. 37–44.

Paller, Gábor – Élő, Gábor (2016b): Power consumption considerations of an agricultural camera sensor with image processing capability, 2nd International Conference on Sensors Engineering and Electronics Instrumental Advances (SEIA' 2016), 22–23 September, Barcelona, Spain.

Porter, M. E. –Heppelmann, J. E. (2014): How Smart, Connected Products Are Transforming Competition. *Harvard Business Review* 92, No. 11. (November), pp. 64–88., https://hbr.org/2014/11/how-smart-connected-products-are-transforming-competition.

Reisinger, Péter – Schmidt, Rezső (2012): Precíziós növénytermesztés – visszatekintés a kezdetekre és iránymutatás a jövőre [Precision Crop Production – Looking Back to the Beginnings and Guidelines for the Future]. *Agrofórum*, vol. 23, issue 10, pp. 40–44.

Scroxton, A. (2016): Interview: How John Deere uses connectivity to make farms more efficient. *Computer Weekly*, February, http://www.computerweekly.com/feature/Interview-How-John-Deere-uses-connectivity-to-make-farms-more-efficient (downloaded: 29.09.2016)

Swinton, S. M. – Lowenberg-DeBoer, J. (2001): Global adoption of precision agriculture technologies: who, when and why? Montpellier: Agro Montpellier., pp. 557–562., https://www.msu.edu/user/swinton/D7_8_swintonECPA01.pdf.

Szármes, Péter – Élő, Gábor (2014): Big Data technológiai megoldások fejlesztése közvetlen mezőgazdasági tevékenységekhez [The Development of Big Data Technology Solutions for Direct Agricultural Activities]. In: Nagy Miklós (ed.): *Networkshop 2014*. Conference, Pécs, Hungary, 23.04.2014 – 25.04.2014 Budapest: NIIFI p. online, p. 13 (ISBN:978-963-88335-5-6).

Szármes, Péter (2014): Kockázatkezelési lehetőségek a precíziós gazdálkodás gyakorlatában [Risk Management Possibilities in Precision Farming Practice]. In: Kovács Norbert (ed.): *Építőkockák*. p. 199 Győr: Universitas-Győr Nonprofit Kft., pp. 179–190. (ISBN:978-615-5298-40-0).

Székely, Csaba – Pálinkás, Péter (2008): Kockázatkezelés az európai mezőgazdasági vállalkozásokban [Risk Management in European Agricultural Enterprises]. *Agrofórum*, vol. 19, issue 11

Tamás, János (2001): *Precíziós mezőgazdaság elmélete és gyakorlata* [The Theory and Practice of Precision Agriculture]. Szaktudás Kiadó Ház Rt.

Whelan, B. M. – McBrateny, A. B. (2000): The "null hypothesis" of precision agriculture management. *Precision Agriculture*, Vol. 2. No. 3., pp. 265–279.

World Bank (2005): *Managing Agricultural Production Risk: Innovations in Developing Countries.* Washington, DC. https://openknowledge.worldbank.org/handle/10986/8797 (dowloaded: 16.04.2014)