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HUNGARIAN FARMERS AND THE ADOPTION OF PRECISION FARMING

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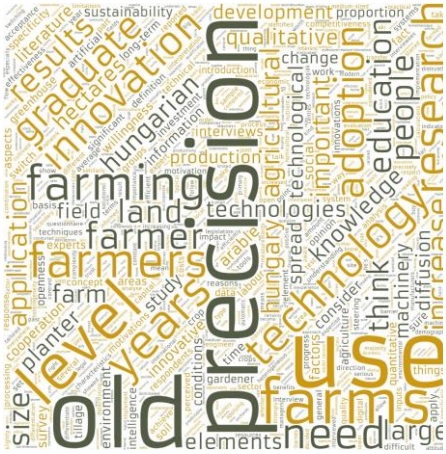

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Abstract: Definitions of precision farming emphasise that it is at the heart of the pursuit of economic, environmental and social sustainability. In our study, precision farming is understood as a form of farming that seeks to optimise and manage efficiently, where technology is the key factor, but is primarily based on human knowledge and willingness to use technology. We discuss precision farming as a social innovation of artificial intelligence. Primarily, the social conditions of the application were the focus of our research, which is characteristically different from economic, financial and productivity approaches. The potential for the application of precision farming varies widely from country to country. Our aim is to analyse the diffusion and limitations of precision farming in Hungary and the motivations of farmers. In our qualitative research, we interviewed 60 precision farmers and 10 experts about their perceptions of precision technology and their motivations and barriers to the use of AI. Our results show that the main barriers to the uptake of precision technologies are the low education level of farmers, their inexperience, low interest level and lack of commitment. They are not aware of the benefits of precision technologies and do not take the time to acquire information and knowledge. There is a lack of willingness to cooperate and a very low level of trust among Hungarian farmers.

Keywords: precision technology diffusion, farmers' opinion, sustainability

Absztrakt: A precíziós gazdálkodás definíciói azt hangsúlyozzák, hogy annak a gazdasági, környezeti és társadalmi fenntarthatóságra való törekvés áll a középpontjában. Tanulmányunkban a precíziós gazdálkodáson egy optimalizálásra és hatékony gazdálkodásra törekvő működési formát értünk, amelyben ugyan meghatározó a technológia, de elsősorban az emberi tudásra és a technológia alkalmazása iránti hajlandóságra épül. A precíziós gazdálkodást mint társadalmi innovációt tárgyaljuk, A precíziós gazdálkodás alkalmazásának potenciális lehetőségei országonként rendkívül eltérőek. Célunk a magyarországi terjedésnek és korlátainak, valamint a gazdák motivációinak elemzése. Kvalitatív kutatásunkban 60 fő precíziós gazdálkodót és 10 fő szakértőt kérdeztünk meg a precíziós technológia megítéléséről, valamint a mesterséges intelligencia használatának motivációiról és korlátairól. Eredményeink szerint a precíziós technológiák terjedésének legfőbb akadálya az agráriumban dolgozók alacsony iskolázottsága, a gazdálkodók tapasztalatlansága, alacsony érdeklődési szintje, az elkötelezettség hiánya. Nem ismerik a precíziós technológiák előnyeit, és nem szánnak megfelelő időt az információk megszerzésére, a tudás elsajátítására. Hiányzik a hajlandóság az együttműködésre, a magyar gazdák körében nagyon alacsony az egymás iránti bizalom szintje.

Kulcsszavak: precíziós technológia, precíziós technológia terjedése, fenntarthatóság

Highlights

- The uncertain conceptual understanding of precision farming is an obstacle.
- Openness to precision technologies among younger farmers is not higher than among older ones.
- The Hungarian public education system does not prepare professionals for innovative agricultural technologies.
- The main barrier to precision farming in Hungary is the low level of education and inexperience.
- Hungarian farmers lack the willingness to cooperate and have little trust in each other, which hinders the sharing of knowledge.

1. Introduction and literature review. Precision farming in Hungary

This paper discusses the social conditions for agricultural innovation and the use of artificial intelligence through the example of precision farming (PF). Our aim is to analyse the motivations for and constraints on the penetration of precision farming in Hungary.

In contrast to Western farmers, whose transition to precision farming is being driven by *rational calculation* (Barnes et al 2019, Adrian et al 2005) *other factors motivate this switch* in Hungary (Oláh-Popp 2018, Balogh et al 2020). Analyses of a sample representing all Hungarian crop farmers show that production and technological utility and the people in the farmer's social network have the greatest influence on the adoption of precision farming, while the farm's past economic performance and the quality of the farmland have a limited effect. This study presented that land size has a disincentive effect of land size willingness to transfer to precision farming, not only in the case of small but also for large farms. The level of willingness to adopt precision technologies is not only limited by the small size of the farm, but also similarly holds back the transition of large farms with monoculture production to PF. The largest farmers' acquisition capacity and network are the best, but they rarely adopted PF and did not even plan for it. The delay in the application of precision technologies attributes to the fact that the technological equipment of their farming is of a high standard, and technological change would entail significant costs and uncertain returns.

International research (Morgan-Ess 1997) has shown a close relationship between *sensitivity to precision farming and sustainability*. Experts highlight the importance of sustainability in relation to precision farming (Milics et al. 2012, Milics et al. 2020, Gaál et al. 2020), but, Hungarian farmers, regardless of the level of education and the size of the farm, do not consider sustainability to be essential for the application of PF. As Balogh et al. (2020, 2021) pointed out there is no strong correlation between PF use and geographical area. Farmers do not consider that territorial differences in social resources and local development levels would have an impact on the adoption of PF.

Compared to Western farmers, *cost effectiveness, the fertility of arable land*, and the knowledge and social capital of Hungarian farmers, play a much smaller role (Balogh et al. 2020). Precision farmers are not motivated enough by competitiveness goals, they are rather only related to increasing profitability. The majority of farmers have no intention of increasing their competitiveness with innovative developments (Balogh et al. 2021).

Precision farming is most widespread in the USA, Europe, Argentina, Brazil and Australia (Fountas et al. 2005). This technology is used in the USA to the greatest extent, where two-thirds of farmers used precision farming techniques in 2016. Yield mapping, differential fertilizer application and vehicle navigation and automatic steering are the main applications of precision techniques (Griffin et al. 2017, Regan 2019). Technology adoption requires a learning process of two to three years (Popp et al. 2018) and this is also the reason why analysts rightly emphasize the shortcomings of the skills of farmers and employed workers in Hungary criticizing the general level of vocational training (Lencsés and Mészáros 2020).

As Milics et al. (2022) state, in the three V4 countries, Czechia, Slovakia and Hungary, there is continuous progress in the spread of data-based agriculture, although all three countries built their databases using different methods and use other legal instruments for regulation. In Hungary (Bai 2022), based on the National Chamber of Agriculture's 2019 estimates, the adoption of precision technologies is increasing year by year (Bai et al. 2022). In 2019, 23% of crop farms reported using this technology. This is 2% higher than in the previous year, but shows a threefold increase compared to 2016. This is only slightly below the EU average, where, according to Jóri's estimates (2019), the share of precision farming among farmers can be put around 25%. Two thirds of domestic farmers indicate that they use at least one of the 10 precision technologies listed (NAK 2019), with the main field crops being wheat and maize and, to a lesser extent, oilseeds, and in horticulture for greenhouse crops. 79% of farmers using AI are satisfied with the results achieved. Of the various precision technologies, GPS (58%), line guide (47%) and automatic steering (24%) are the most widely used. The proportion of assets they own themselves is

higher. The rental of precision equipment only reaches 50% for fleet tracking and the use of drones (CSO, 2021).

Among the factors influencing uptake, the use of digital tools has grown dynamically (from 60 to 86% for computers, from 33 to 51% for tablets and from 56 to 73% for mobile phones in 2018) and the vast majority of farms (93%) have at least one of these tools available (NAK, 2019). The introduction of precision tools is not limited in our country by any lack of basic infrastructure. In addition to the digital background, the uptake of precision farming is also strongly influenced by the size of the farm, as the use of their own precision devices and the deployment of the system entail significant investment and consequently high fixed costs (depreciation, consultancy) during their operation, where economies of scale occur to a significant degree. This is well demonstrated by the investment costs estimated by Kemény et al. (2017). For a company with 800 hectares of land, the application of precision technology increased the annual fixed costs by HUF 57,000/ha (Bai et al., 2020), so, for cereals, it meant that a 1 to 1.5 t/ha increase in the break-even point must be yielded through precision technology. This value can be significantly lower for larger farms with well-utilised machinery.

Since 1990, the Hungarian rural economy and agriculture have undergone a major structural and ownership transformation (Csurgó et al. 2019, Kovách et al. 2022). Forty-one percent of the 4.8 million ha of agricultural land in Hungary is farmed by farms larger than 300 ha; the share of these large farms is only 4.7% for vineyards and 8% of the fruit-growing areas (CSO, 2021). This may provide much more favourable conditions for uptake compared to the EU average, where 86% of farms have fewer than 20 ha (Jóri, 2019). In Hungary, we are still witnessing a concentration of farm sizes; since 2010, there has been a large increase in the amount of land per farm in all farming sectors (CSO, 2021, Kovách 2016).

From this point of view, the fact that the average age of farmers is increasing and the proportion of decision-makers under 40 is below 10% is not an advantage for domestic adaptation. Only 6% (women) and 10% (men) of managers have a tertiary level qualification (CSO, 2021). In addition to personnel conditions, machinery manufacturers do not facilitate the transition to precision technologies, as the technologies and developments of different companies are not compatible with each other and are therefore not suitable for a uniform management of the database, and domestic farmers typically use several brands of machinery (Hadászi, 2018).

We follow Drucker's approach (Drucker 1985), according to which innovation, in our case, the adoption of precision farming, is not only an economic, technical or technological change, but also a social category. Following this observation, we decided to contribute to the international literature with a qualitative study by asking precision farmers about their understanding and perception of the concept, as well as their motivations for and constraints on the use of artificial intelligence.

2. Research background, methodology

The analysis in our study is based on a qualitative study. However, the interview study was preceded in time by a questionnaire survey. The central question of our research was the social determinants of agricultural innovation. Among farmers engaged in arable crop production, we investigated the knowledge of precision farming, the conditions determining the diffusion of the technology and the motivations for switching to it. Quantitative data were collected in 2019 among Hungarian crop farmers who farmed at least two hectares according to the AKI test farm database. The sample was 604 persons, representative of crop farms The results of the cluster analysis of the quantitative study allowed us to interpret the attitudes of Hungarian farmers towards precision farming. The results have been summarised in a previous study. (See more details: Balogh et al. 2020). The results of the questionnaire survey have stimulated the current interview research to gain a deeper understanding of precision farmers and to better understand the categories that have been established.

The large farmers, regardless of whether they have a lower or higher-level qualification, or whether they use precision technologies or not, are above average in terms of information on PF, but also on other issues affecting the agricultural sector. The specificity of the situation in Hungary is precisely that farmers who are the least willing to invest in precision technologies in the future who are most informed about

precision technologies. The opposite is true for farmers with low or no qualifications, low turnover and small farm size. Although they run their farms relatively efficiently, they are extremely poorly informed about PF. Low knowledge capital and small farm size are associated with low levels of professional-relational-informational capital, leading to a kind of isolation of them. This is also problematic because under-educated smallholders are reluctant to invest in precision technologies and, in an isolated environment, this attitude is unlikely to change gradually. The other types of farmer's groups, are mostly open to PF. With a medium to small farm size and relatively high (secondary) education, they are more informed but would require some information on precision farming; they are very dissatisfied and critical of the information flow and access to information and knowledge transfer opportunities in Hungary.

The impact of the legal-political environment on PF was perceived by the largest farmers to be of paramount importance, in particular the need for legislation to ensure the security of long-term land tenure and fair taxation rules aligned to PF. On the other hand, low-skilled smallholders do not attach importance to the legal-political environment, do not believe in the positive impact on the spread of PF of fair tax rules tailored to precision farming, and do not consider special regulations essential for the development of the sector in general. Given their situation, they consider long-term, predictable agricultural policy strategies to be the most important. Similarly to large farmers, medium-sized holders, between the largest and the smallest farmers, would consider it very important to have a predictable agricultural policy and legislation that would allow for long-term land tenure security. However, similarly to small-scale farmers, they would find legislation specifically tailored to precision farming less useful. Farmers with small or medium farm sizes, located between the two extreme clusters and open to PF, would also consider legislation that allows for long-term land tenure security and predictable agricultural policies as very important for PF development. At the same time, they do not consider special tax rules important, like all other groups of farmers except large farmers.

As the number of people practising precision farming was low in the questionnaire survey, we decided to conduct a qualitative study in order to test quantitative results and to validate previous results. The dimensions of the interview survey were developed taking into account the results of the questionnaire survey presented earlier. In our qualitative research, we interviewed only precision technology users. We conducted 60 semi-structured interviews with farmers and 10 interviews with experts. In the current research, we wanted to identify the reasons for the adoption of precision farming and explore the factors that facilitate the diffusion of innovations. The analysis was structured around answering three research questions: firstly, we were curious about farmers' own interpretations of precision farming and innovation technology. On the other hand, we wanted to identify the reasons why a farmer would switch to precision technologies, what would encourage the switch. Finally, we asked what factors help innovations to spread and how they can become more accessible to more people. To be included in the sample, farmers had to be involved in precision farming, using at least a minimum level of precision technology. The interviews were conducted by personal contact and the list of farmers' addresses was compiled using the AKI database. In all cases, a verbatim transcript of the interviews was made. The average length of the interviews was 1.5 hours.

In designing the sample, care was taken to ensure that, in addition to the respondents' use of some of the precision technologies, we tried to achieve a kind of national coverage in terms of area. On the basis of which all counties with agricultural activities were included in the sample.

The interview research was based on the analysis of four main dimensions, within which several sub-dimensions were created. The main dimensions of the research are (1) the characteristics of the essence and characteristics of precision farming according to the interviewee, (2) a detailed description of the respondent's farm and farming, (3) opinions on the situation of precision farming in Hungary, (4) obstacles to the spread of precision farming according to the respondent.

Tab 1. Number and type of interviewees by county. Source: Own editing

County (NUTS 3)	Type of interviewee	Number of respondents
Bács-Kiskun	gardener, planter farmer	1
	field farmer	5
Békés	field farmer	2
	gardener, planter farmer	4
Borsod	field farmer	2
Csongrád	field farmer	2
	gardener, planter farmer	2
Fejér	gardener, planter farmer	1
Hajdú-Bihar	field farmer	17
	gardener, planter farmer	2
Heves	field farmer	2
Jász-Nagykun-Szolnok	field farmer	6
Pest	field farmer	2
Somogy	field farmer	3
	gardener, planter farmer	1
Szabolcs-Szatmár-bereg	field farmer	4
	gardener, planter farmer	1
Veszprém	gardener, planter farmer	1
Zala	field farmer	2
Experts on precision farming		10
Total		**70**

3. Reasons for the introduction of precision farming and factors facilitating the distribution of innovations

In this section, we use our qualitative research conducted among farmers who have adopted precision farming as a basis to show which factors interviewees consider to be the most important in influencing the uptake of precision farming.

3.1 Interpretation of precision farming and innovation technology

One of the prerequisites for the adoption of PF and innovation is the participants' adequate knowledge capital. This is particularly important for the spread of PF, as its introduction requires a new approach and a major technological shift. One of the difficulties in the transition to PF is *the interpretation of the concept itself.* Even the literature is divided on the basic concept of PF. Two interviews with leading PF experts illustrate the uncertainties in the definition. An important feature of the response is that the experts do not cite a legal definition, but give their opinions. "What we are saying is that we can then talk about it" introduces the definition by the first expert, and he sums up the response with "I think it is very important". The second expert uses the phrase "in my reading" three times during this short interview. Site specificity is the only common element in the experts' PF definition. The first expert emphasises measurement, data processing, automation and specialisation based on differentiation. In contrast, the second opinion states "I think that precision farming does not mean that I can do something very precisely and accurately now." The respondents quoted are not theoreticians but leading practitioners. The ambiguity of the concept of PF at the expert level suggests that this type of agricultural innovation is an open-ended, continuous series of changes, of which constant technological and IT development is a basic

element, and that this requires new forms of adaptation and change from both producers and integrators, which also needs to be followed by regulation and support.

"We can talk about precision farming ... when it is always based on concrete measurements, and always intervenes on the basis of measured results. These measurements are site-specific. This, together with the heterogeneity of the territory, allows us to react to the heterogeneity of the territory, because it is indeed not homogeneous but heterogeneous. Previous technologies have worked on the principle of generalisation or averaging. The new technology works on the principle of differentiation. .... We want to be able to differentiate if we can differentiate. I think this is very important. That's one part of it. The other part is based on the measurements; based on the measurements, there is a large amount of massive data and, on that, there is a data processing process. At the end of the data processing process, there is an implementation function. And this process is, in most cases, partially or fully automated. This is when we say that we can talk about precision farming" (Expert 1).

"We look at Precision farming as an umbrella term, and when we look at precision farming, in my reading, it breaks down into at least three but mostly four sectors. Precision farming in my reading can take arable, horticultural and livestock lines. And then, when we analyse arable farming, I always keep the emphasis on site specificity. I think that precision farming doesn't mean that I can do something very precisely and accurately, but rather that it means site specificity" (Expert 2).

Farmers' interpretation of PF reflects even more the uncertainty that results from the complexity of PF and the constant renewal of all elements of production. *"Precision farming is, in my opinion, a broad concept and is more expansive than a layman or even a professional might think,"* says a 60-year-old precision farmer. A middle-aged farmer, who has never defined for himself what PF is all about, gave this definition: *"so it's a combination of traditional production and modern technology to make agricultural production as efficient as possible. And there can be quite a few branches and offshoots."* (47 years old). The complexity of PF is a determining element in the uncertainty of its definition. It is difficult for respondents to judge at what technical and IT level a farm can be considered precision farming. *"I think I would say of about three people in the country that they are precision farmers. All the rest represent just elements of it, anyway. I know very few companies that are, let's say, already fully precision farming, so they use all the elements of precision. So, who is a precision farmer? You can't talk of it in this way."* (47 years old). *"Automatic steering is still a long way from calling ourselves fully precision farmers."* (27 years old)

The majority of farmers see PF as a set of conditions to which they have to *adapt constantly*. The challenge of constant renewal is, according to farmers, a previously unknown component of (agro)innovation, which opens up *a fundamentally new era* in terms of approach, renewal of knowledge capital and production practices.

The PF definitions are dominated by production, technical and IT aspects. *Environmental impacts and social consequences* were not mentioned by any of the respondents in relation to the concept of PF. *Rational decisions* were only linked to the concept of PF in a single case. *"That it is the result of an activity or a process where decisions are made on the basis of an informed, objective result, and the machinery's capabilities are sufficient to implement them." 31 years old.* It is known from the international literature that a major motivator for switching to PF is *higher income,* but this is not reflected in the perception of Hungarian farmers on its own, but only in combination with the introduction of new techniques. The definition of PF includes *production, technical* and, separately, *IT* criteria. Most respondents identified the use of *IT* as the most important element of PF.

"First of all, digitalisation comes to mind; that is, everything operates on a digital basis, and then the other terms come to mind, such as zoning, differential application, productivity maps, zones, variable planting density, fertiliser application, robotic steering, precision steering and so on." (36 years old). *"I think that those farmers who already use some kind of signal or automatic steering, you can say that they are already precision farmers, but it is such a complex system from tillage to harvesting, through irrigation, nutrient evaluation and sowing."* (27 years old)

Technical innovation also appears as a key feature of PF.

"By precision farming, I mean a complex, not only a tillage system; I mean a complex technology, which is mainly dominated, or should be dominated, by knowledge." (60 years old)

"I a consider precision farmer as someone who, based on soil test results, is able to design, say, the replenishment of a nutrient, and is capable of actually designing it in software and applying it to his land in a variable dose. Or he can do the same thing for a seed, or even for a pesticide; he doesn't cultivate the entire area, but he can distinguish zones within his land and manage them consciously and separately, relying on data." (43 years old)

"Actually, technological discipline, or precise adherence to technology, already constitutes precision farming. Well, to be honest, what I have thought or think of from my own head is intensive farming underpinned by rather serious technical improvements." (57 years old)

The impact of PF on *production efficiency* is a dominant element in the opinion of older farmers.

"starting with the soil tests, knowing the soil, all our crops, their fertilizer and planting density reactions, transferring them through the maps. In implementation: the field, not just specifically as controlling machinery, but in my understanding of precision farming, it is a totally comprehensive method." (52 years old)

"I mean, what comes to mind on the first round, that application in the field is site specific and differentiated." (60 years old)

"to produce efficiently and effectively, to exploit resources well, to perform the operations in time, but always using the right input material, so making production more economical." (60 years old)

3.2 Why do they start to use PF?

We investigated the reasons for the adoption of PF among Hungarian farmers, what motivated them to use technological innovations and what aspects motivated their decisions to change their attitudes and investments. Prior to the analysis, we distinguished between two groups of farmers, arable farmers and horticultural farmers, based on the type of cultivation, on the basis of their different approaches to PF, with even fewer technological elements being established and diffused in horticulture in Hungary. However, we did not find any major differences between these two groups in their reasons for their introduction, and, where we did find minor differences, we will discuss them separately.

"Precision, I say, in the fruit growing sector, I think is still in its very, very early days, and it's just such a tentative step, so you're not going to find many people here who say, 'oh, well, we're already in this thing', It certainly exists for arable farming, and there's serious progress there." (71 years old, graduate, 400 ha of orchards)

"I think that the level of what we now call precision farming – let's say I have an insight into plantation farmers – I can tell you that precision farming means plant protection forecasting, nutrient application, which we usually do by means of leaf analysis for some partners, and those who are interested in what data is in it in my opinion, are 1% or 2%, and the others are not interested in that either." (40 years old, graduate, 45 ha apple orchard, consultancy company)

The first motivation we identified among farmers is to increase their financial efficiency, higher profitability, and economic reasons for deciding to adopt technological elements. They expect less of an increase in yield from the improvements and more of a reduction in costs. These farmers are characterised by conscious improvements, making constant calculations in order to achieve higher profitability.

"The larger farmers who work in a system and integrate even several smaller farmers, and they cultivate their land and want to make a profit, then they really have to deal with it. Because if I put out one forint, then I shouldn't pick one forint, and not minus one, but there should be a plus there. And to go in that direction, you have to deal with the soil." (45 years old, graduate, precision service provider, small family farm)

The vast majority of farmers start PF because they have already seen good practice and an example to follow. Among both horticultural and arable farmers, a mention of conferences and study trips abroad is typical, and they often constituted the primary motivation for them. Most of them use the innovative technologies that they have already seen working effectively in the crops they grow.

"I think that you definitely need a willingness or an interest to do it, and I see farmers who are always a bit innovative, who aren't going in the direction of the familiar, but are always looking for new opportunities, new technological solutions instead, which they themselves might not even know if they will bring any result." (31 years old, graduate, cultivates 800 ha of land, on 2500 ha of land they provide mechanical services to local farmers)

There are also farmers who apply very few elements of precision technologies; for them, the starting point is "not to be left behind...", they are not sure of the return on investment, but they trust in innovative technologies and their ability to help the workforce.

"It's a high-priced technology; we're not even sure it's going to pay for itself. (...) You can also reduce the time spent at work in the fields. So the wages that we pay our boys, there's still some reserve in it." (36 years old, graduate, farms 1500 ha)

The argument for the introduction of precision technologies in both farming communities was the issue of labour, but this was approached in a slightly more nuanced way by the two groups. While, for arable farmers, the key element was to make the jobs of the employed workforce easier and more efficient, and the reduction/decrease in the labour headcount was not mentioned even once, in horticulture, the adoption of precision technologies is seen as important due to the steady decline in manual labour, as a replacement or substitute for human labour in the future.

"The other is that we talk about precision farming. The question of specialists or tractor drivers is becoming more and more pressing. So, in order to, say, do well with a crop, you had to concentrate the harvesting, everything, so that people are exploited; machines are exploited..." (43 years old, graduate, 1800 ha of land in integration)

"And anyone who I think is trying to catch up, he's trying this and also used it in the past. And I think its importance will become more and more prevalent in the coming period, mainly because of the labour shortage." (71 years old, graduate, 400 ha of orchards)

Farmers reported very different use of technology by land use and often also by crop. Within the PF, the use of technology shows the highest level of innovation use in greenhouse production; these farmers see innovation as the basis of their competitiveness. A significant proportion of the farmers surveyed use only low-input and low-precision technologies, and are novice users.

"It varies from one sector to another: if I say that, in an orchard, someone who uses irrigation, pest monitoring, maybe a weather station and frost protection, in my reading he's a precision peach farmer. Now, if we go into a greenhouse with the same tools, that's a low-cost solution. That's why we use these: don't get me wrong, it's been a big thing for three years now, but we've been precision farming for ten years because we wouldn't be able to do it any other way. Obviously, it's brought two things, first of all, very high investment costs. A hi-tech greenhouse that is suitable for the needs and is competitive is 500 million forints..." (51 years old, vocational secondary school qualification, 2 ha hi-tech greenhouses)

There are no typical demographic indicators of openness to PF as reported by farmers. Age and educational attainment also show no greater willingness to use innovative elements. However, the need to produce better quality is typical of those who use modern technology and the issue of prestige also appeared. In the farming community, farmers producing more efficiently are considered to be of a higher rank; they receive more respect from the community, and they see PF as a primary means of efficiency.

"It doesn't increase confidence, it increases respect for me. It also shows that it's more worthwhile to work for us because we're more committed than others." (36 years old, graduate, farms 600 ha)

Furthermore, openness to PF and the incentive to innovate can be increased by integrator organisations and educational institutions, and the role of R&D is increasingly appreciated by farmers. They also see

the need for farmers to be open-minded. In their opinion, farmers who want to get information about precision technology can do so in any case.

"So what I say to that is that some people who have the interest and read a lot of literature, they will certainly come across it, and then if they see that they can apply it in their own field, they certainly can. I think that the direction that has now begun is that they are interested in these things, from universities to machinery manufacturers – and this is a very important line – or nutrient management companies. So I think that the knowledge that they are passing on, or to be passed on, is very good, and I think there is knowledge in it. There aren't many things that I am so completely satisfied with. I think there's a big upswing in that too, and then I'm not sure that this momentum will remain unbroken..." (71 years old, graduate, 400 ha of orchards)

3.3 Factors that help the spread of innovations according to precision farmers

Factors contributing to the diffusion of PF were investigated in two groups of sectors, arable farmers and horticulturists. We wanted to know what conditions those farmers who already use precision technologies would consider necessary for the spread of innovations among Hungarian farmers. One of the most important factors highlighted was the need to increase the level of expertise and education, and the primary objective would be knowledge acquisition. The low level of education of agricultural workers was mentioned as a serious problem, which is a major barrier to the diffusion of innovative solutions.

"The old habits are still in place, rather than the new and modern ones, and secondary education should be organised differently." (67 years old, graduate, farms 1200 ha)

Another important aspect in the spread of PF could be an increase in the motivation level of farmers, especially in terms of commitment, experience and willingness to invest time. It is also the responsibility of farmers to employ workers who are open, trainable and willing and able to use the technology.

"Persistence is the barrier to spread. Besides, the whole of agriculture in Hungary is completely old, and young people have no financial capacity. If somebody inherits some land, they usually sell it. And the old people... 'the land should be on the back burner in the autumn', and then we'll see what happens to it. I don't see much imagination in that either, I'll be honest." (35 years old, farms 900 hectares, agronomy graduate)

"I think you just need a general user knowledge, if you have a more serious car with a touch screen display, you can handle it. You need a sense for it of course, but it doesn't need to be outstanding. They've done a pretty good job of dumbing down the machines so that the average person can understand it. I think people who go into this are much more attentive, much more skilful producers." (46 years old, 300 ha farmer, lawyer)

A significant barrier to the uptake of PF is that a significant proportion of non-precision farmers are not aware of the benefits of the technologies. It would be important for them to be able to learn about good practices, best practices and methods, but they do not see technological solutions in their own environment that can be adapted to their own farm characteristics. This is also the result of the fact that the proportion of precision farms in Hungarian agriculture is so low that they do not yet serve as a model for others to follow.

"The peasant is terribly clever, if we were to say to him, look, today he can buy a precision technology for 100 forints, tomorrow he can pocket 130 for it on the market, all Hungarian farmers would buy it, but the problem is that this one step is missing. In other words, no one can see when and how the money and energy invested will be recouped. Everybody is tasting it, getting to know it." (60 years old, agricultural engineer, farms 1000 hectares)

"Today's agriculture is not really about highly skilled people, the other thing is that we lack the volume of land to do it. In Hungary, there is still the attitude that an area sown in the spring must be black, because if not, what kind of work is it... People are still influenced by visual thinking. In many cases, the entrenched, ingrained things sing still, and not the new and modern. To do this, we need to organise secondary education differently." (69 years old, agricultural engineer, farms 1200 hectares)

Farmers with smaller landholdings would see the possibility of spreading PF primarily in the form of cooperation and association. Joint investment, development and the joint use of expertise are seen as the most important tools. At the same time, they currently see no chance of this in Hungarian agriculture, because farmers are not open to cooperation and tend to isolate themselves from each other.

"Thinking is... Every farmer should turn the knob one or two turns in the positive direction, so that they don't feel averse to cooperation. They are distrustful, very distrustful of each other." (66 years old, graduate, farms 70 ha)

Also among those with smaller landholdings, the fact that farmers who do have precision applications are only renting them because the size of the land does not allow for a return on investment makes it difficult to spread PF as well. They mainly wait, hoping that in time, as precision technology spreads, access will become cheaper.

"Obviously, the size of the farm is crucial, because you need a certain amount of land to be able to calculate the return on investment of the PG. So I wouldn't think that for arable crops, 30–50 hectares is worth thinking about precision farming for yourself. In contract farming maybe, but I think that yes, acreage size does matter. And expertise is paramount I think." (53 years old, agricultural engineer, farming 500 hectares)

One of the most dominant groups not planning to introduce PF are farmers with high quality, homogeneous land and high yield averages. They are those who are not precision farmers but have a high level of technological development and do not plan to switch to precision technology. In their opinion, those farmers would need PF, or more precisely, those who farm mixed fields with large intra-field variations, would have the chance to achieve more cost-effective and efficient production. For them, it may be worth investing in new, innovative technologies.

"Well, we started because we have heterogeneous areas, or most of our areas are heterogeneous. When we started doing this, we wanted to increase the amount of inputs we were applying to increase yields, but we had to see that it was completely unnecessary to increase the amount of inputs we were applying to very weak areas, because there are limiting factors that will make it impossible to use." (50 years old, agricultural engineer, farms 800 ha)

"PF is very important in heterogeneous areas. I am sure that those who farm in such areas need to save inputs. I would like to believe that someone will pave the way in homogeneous areas, pointing the way in the right direction, but I can't yet imagine the effectiveness." (40 years old, agricultural engineer, farms 1300 hectares)

Farmers mentioned, as a prerequisite for the spread of PF, the need to create knowledge centres where farmers can test precision systems in local conditions before buying and applying them. These centres could play an important decision-support role by providing information and could also offer protection in negotiations with machinery suppliers.

"I am not aware of any targeted support to encourage precision. I hear it everywhere, in all the journals and on the Internet, that we need to introduce precision, but the only problem is that there are no centres set up to test it, not to sell it, but to find out how well it works." (36 years old, graduate, farms 600 ha)

"There should be much more extensive flow of information. Also the practical part. But actually it's everywhere, from machinery sales to tillage systems. Because that's how I see it all together, that's why I want to implement precision farming with as little tillage as possible. Then it will be a good system." (36 years old, graduate, farms 600 ha)

4. Discussions and results

The aim of this study was to analyse the motivations and limitations of PF adoption through qualitative research interviews with precision farmers. We analysed the information from the interviews according to three aspects.

The first topic was the *interpretation of PF and the evaluation of innovation technology*, which was difficult to define even for practical experts and managers dealing with PF. In principle, interpretation and understanding is a matter of consciousness, but the uncertainties experienced in this can be a strong obstacle to the spread of precision techniques and artificial intelligence in agriculture.

In international literature, the Theory of Planned Behaviour (TPB) by Ajzen (1991) is mostly used to understand farmers' evaluation of innovation techniques, which can have a strong impact on the adoption of technologies. Farmers who perceive technological innovations as beneficial are much more ready to accept and apply them (Pino et al. 2017), which can be strengthened by external normative pressures aimed at protecting the environment (Aubert et al., 2012). According to Lynne et al.'s (1995) research, there is a positive relationship between perceived behavioural control and technology acceptance, although other research (Pino et al 2017) did not confirm this relationship. The characteristics of the perceived need, the perceived benefits, the effectiveness or the perception of risks can have a significant impact on the evaluation and adoption intention of a precision innovation (LI et al 2020).

In response to *the second set of questions*, interviews revealed additional aspects of the question "why do farmers choose precision farming" For agricultural employees and consultants, the adoption of precision techniques is facilitated by perceived ease of use and perceived usefulness (Far and Rezaei-Moghaddam 2017). The study of Shaikh et al. (2022) and the work of Chabot et al. (2018) showed that the assumption of the innovative usability of the new technology is fundamentally related to the intention to use it.

Using the Technology Acceptance Model, Venkatesh and Davis (2000) showed, similarly to the study by Rose et al. (2016), that the acceptance of new technologies is increased. if it makes your own work more efficient or easier. (Stræte et al (2022), on the other hand, pointed out that the adoption of innovative technologies is greatly promoted by special-purpose subsidies. The predominantly rational calculations typical of Western farming societies (Barnes et al. 2019, Hansson-Kokko 2018, Charatsari et al. 2017) are a motivating force for only a small segment of Hungarian farmers. This observation is also confirmed by quantitative research (Balogh et al. 2020). In our qualitative research, motivations such as *"a model to follow" or "good practice"* appear in the initiation of technology use. Some of the farmers feel that they do not want to be left behind and that their primary motivation is their current position in farming society. One of the most frequently recurring elements along the lines was the issue of labour, where we also found a difference between horticultural and arable farmers. The need to make the work of the hired labour easier and more efficient and the continuous reduction of manual labour are also mentioned. The demographic indicators (education, age, etc.) of precision farmers are not uniform, as the interviews show, nor is there a greater openness of the younger generation in this area. Respondents noted that *educational institutions* should increase students' motivation to use innovative technologies.

Thirdly, according to precision farmers, the *main barriers* to the uptake of PF in Hungary are the *low education and inadequate skills* of those working in the agricultural sector. Farmers' inexperience, low level of interest and low level of commitment are also problems. They are not aware of the benefits of PF technologies and do not take the time to learn the technical information. The motivation level of farmers could be increased if they learn about successful methods that apply technological solutions adapted to the characteristics of their own farm. They would consider it important to join forces and form cooperatives in order to pool expertise, joint development and joint investment. However, there is a *lack of willingness to cooperate* among Hungarian farmers and a *low level of trust* in cooperation. There is also a *lack of decision-support knowledge* centres capable of testing precision systems in local conditions.

As a summary, we can point out that the spread of PF, for which the arable land productivity conditions would be excellent, is more strongly related to the state of human capital in Hungary compared to the core areas of PF use. In this regard, the current generational change of farmers can bring positive progress, since the younger generations of farmers, especially in large and medium-sized farms, have a much higher level of education than their predecessors.

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