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Economic benefits of precision weed control and why its uptake is so slow

Innovation in agriculture ensures the widespread use of the most up-to-date technology. One such technology is precision crop protection, which meets the requirement of environmental and economic sustainability. The applicability of precision crop protection has been verified by several studies and in practice, but its uptake is very slow. Examining the economic relationships between potential savings and pests at the European Union level, this paper shows that the savings in pesticide use following the adoption of precision plant protection can be 30,000 tonnes (calculated using the current dose levels) per annum. If approximately 30 per cent of the crop producing and mixed farms larger than 16 ESU apply this new technology, the environmental burden will be reduced by 10-35 per cent. From a survey of 72 Hungarian farmers we found a positive correlation between the size of the farm and the adoption of precision farming technology, and those farmers in the survey that had implemented precision crop production estimated that the consequent change in income had been positive. Thus, at a certain farm size and farming intensity, precision crop production is a real, environmental friendly farming strategy option, through which each farm can generate an income that covers at least the economic conditions of simple production. By encouraging environmentally friendly farming practice, precision crop production can meet the requirements of the proposed green component of Pillar 1 of the Common Agricultural Policy for the period 2014-2020.

Keywords: greening, precision farming, pest control, technology uptake.

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Introduction

Precision farming is a holistic system, a technology that allows target oriented treatments, thus managing the spatial and temporal variability within an ecosystem, by applying spot treatment applications. It has been shown that the implementation of precision crop production can result in savings in the use of pesticides, while savings can also be expected regarding fertiliser use, depending on the objective of production. (Godwin *et al.* 2003; Timmermann *et al.* 2003; Swinton 2005; Dillon and Gandonou 2007; Chavas 2008; Guthjar *et al.*, 2008). Precision crop production is compatible with ecological, economic and social sustainability. Social sustainability means the sustainability of food, energy and industrial production, and compliance with economic criteria in terms of the producer, as well as the sustainability of the environment.

The application of precision technology in crop production may ensure more efficient production for the grower along with a lower environmental impact. Precision farming could result in less agrochemical being distributed in the environment, and it also could be one of the basic pillars of efficient agriculture while large-scale production structure, investments, organisational structures and operational mechanisms remain. Earlier studies estimated 20-60 per cent pesticide savings owing to precision plant protection and 0-30 per cent savings in fertiliser use depending on the yield homogeneity (Lowenberg-DeBoer and Swinton, 1997; Batte and van Buren, 1999; Pecze, 2006; Rider *et al*., 2006). Also, for the producer this method of farming can be a tool for reducing the risks associated with production. With the appropriate implementation and combination of technological elements in crop production, the uncertainty of crop yield can be reduced and the reliability of the farmer's income can be increased (Auernhammer, 2001; Takács-György, 2008a; Chavas, 2008). Accuracy is necessary during the correct application of precision technology, but often this is a factor that obstructs its use on farms (Arnholt *et al*., 2001; Sinka, 2009).

One of the less examined areas of the economic relationships of precision crop production is precision crop protection. On the basis of several years of plot-level trials, real savings in agrochemical use (60 per cent) resulting from using spot treatments of precision weed control are reported by Hall and Faechner (2005). Other authors (e.g. Gutjahr *et al*., 2008) stress that actual agrochemical savings do not necessarily mean similar levels of cost savings. Using simulation model examinations that considered also the economic impact of locally specified weed control, Toews (2005) estimated that the income difference can be between EUR -25 and EUR +40 per hectare compared to the treatment of the entire surface. This difference is also affected by the distribution of weed cover, sowing shifts, agrochemical costs and weed competence. In spite of the fact that the technical-technological resources for producers are available, crop protection is the least used among the existing precision crop production components; yield mapping, precision fertilising and lime management are more frequently used (Timmermann *et al.*, 2003; Jensen *et al*., 2012; Lencsés, 2012).

Earlier studies have shown that the conversion to precision crop production is limited by the need for additional investment and the availability of labour (Weiss, 1996; Lambert and Lowenberg-DeBoer, 2000; Godwin *et al*., 2003; Takács *et al*., 2008; Takács-György, 2008b). However, the design of additional equipment does not mean a disproportionate investment burden. In spite of approaching the twentieth anniversary of precision farming technology, it is still in the early adoption stage. Precision farming, as an innovation in agriculture, can be considered as 'technology push' innovation. The cooperation of several different actors in the food chain is necessary in the case of precision technology, although the process is different from the market-focused technology development system proposed by Fenyvesi and Erdeiné Késmárki-Gally (2012). Generally, farms cultivating bigger areas of land with a mixed structure use rather more elements of precision technology than do their smaller farm counterparts (Takács-György,

2008a; Jensen *et al*., 2012). Only five per cent of farms applied at least one precision element of technology in the United Stares in 1998, on farms larger than 1200 ha (McBride and Daberkow, 2003), while Swinton and Lowenberg-DeBoer (2001) reported that only 1-5 per cent of Austrian, Brazilian, Danish, English and German farmers used precision technology in 2001. Over 400 farmers (one per cent of the farms registered in the Farm Accountancy Data Network (FADN)) applied precision technology in Denmark, of which 80 per cent were bigger than 200 ha, but only ten used more than one element (Pedersen *et al*., 2010). When the costs of data collection are included in the costs of extension, the frequency of precision services was extended in the United States not only on large farms (Griffin and Lowenberg-DeBoer, 2008). The results of Jacobsen *et al*. (2011) also illustrated the low percentage of farms using more than one precision element and underlined that farmers applying precision technology are bigger farms. Reichardt and Jürgens (2009) reported a low and moderate adoption of precision farming in Germany and emphasised the need to improve the official advisory service.

The question is, what can be the role of precision crop production in meeting the requirements of the proposed green component of Pillar 1 of the European Union's (EU) Common Agricultural Policy (CAP) for the period 2014-2020, which is intended to encourage environmentally friendly farming practice? Under the proposals, farmers carrying out organic production will automatically be entitled to complementary subsidies (EC, 2011). According to Wolf and Buttel (1996), precision farming is an abiotic factor, which is the ultimate tool for the reform of agricultural production. Precision crop production clearly belongs to this type of alternative farming strategy.

In order to determine the type and intensity of farming that is most suitable for the environment, the losses and the negative consequences of pests and diseases for environmental and human health should be considered. Based on different calculations, yield losses caused by pests (biotic stress) can be significant, up to 40 per cent of the potential yield. Of this, yield losses caused by weeds are 10-12 per cent; those caused by pathogenic organisms are 18-20 per cent, and those caused by insects account for 8-10 per cent (Auernhammer, 2001). However, the demand of society to reduce the use of pesticides, both in terms of the quantities applied and the frequency of use, can be satisfied in a number of ways (Smith and Reynolds, 1966; Lambert and Lowenberg-DeBoer, 2002; Szentpétery *et al*., 2005).

There are many direct and indirect economic (agricultural policy) means of reducing the use of crop protection chemicals. The tax on these chemicals in itself does not reduce their use if it is not paired with the compensation of revenues (Falconer and Hodge, 2000). Skevasa *et al*. (2012) confirmed through the use of models that, in contrast to taxes on pesticides, the low toxicity pesticides, pesticide quotas and the support of environmentally friendly R&D results can reduce agrochemical use. From studies of French vineyards, Lescot *et al*. (2011) have found that both environmental taxes and green subsidies can contribute to the returns on precision means. They have also concluded, however, that the ratio of shifting and the number of applied elements was low within the examined group. The poor financing situation and the high indebtedness of farms (owing to the financial crisis) were highlighted among the possible reasons.

Our research objective was to estimate, taking into account the considerable capital demand involved in shifting to precision crop production, as well as the advanced technical expertise that is necessary and the changing management tasks, the size of area on which precision agrochemical use can be introduced, how much agrochemical can be saved and what changes will result in the competitive position of the producers. The aim of this paper is to examine, firstly, the potential role of precision crop production in the reduction of environmental burden and, secondly, why its uptake is so slow in spite of its confirmed environmental and economic benefits. We advance two hypotheses:

- H1: If an appropriate number of farms shift to precision crop protection, measureable amounts of pesticides can be saved at the EU-25 level, and thus the objectives of greening can be reached by using precision technology;
- H2: Higher scale of farming and higher qualifications of farmers can enhance the expansion of precision crop production.

Methodology

Estimation of savings in pesticide applications

The starting point of our research was that, at the EU-25 (i.e. excluding Romania and Bulgaria) level, conversion to precision crop production of a specified area of the farm can result in considerable savings. These savings can be related primarily to crop protection, which also means a reduction in the environmental burden. Our calculations are based on Farm Structure Survey (FSS) data (Eurostat, 2009). It was a starting condition of our research that arable farms and mixed farms would switch to precision farming only if they are above a certain size, because of the additional equipment required for the technology adoption.

In the EU, 240,000 farms belong to the 16-40 ESU class, covering 4.2 million hectares, 139,000 farms belong to the 40-100 ESU class, cultivating 5.9 million hectares, and the number of farms over 100 ESU is 77,000, which together cover 11.3 million hectares. Our assumption was that farms above 100 ESU are able to switch to precision crop production by making their own investments based on their farm size and production level, while farms within the 16-40 and 40-100 ESU size classes can convert by using shared machinery.

The degree of savings in relation to the number of converted farms and the intensity of production (agrochemical use) was examined by scenario analysis. Based on the literature examining the penetration of the elements of precision plant production (Jacobsen *et al*., 2011; McBride and Daberkow, 2003), the proportions of farms converting to precision farming were set at 15, 25, and 40 per cent using pessimistic, neutral and optimistic scenarios, respectively. The expected savings in pesticide use, 25, 35 and 50 per cent were determined from the literature (Batte and van Buren, 1999; Pecze, 2006; Rider *et al*., 2006; Chavas, 2008).

Table 1: Nitrogen fertiliser and agrochemical use in selected groups of European countries in 2008.

Country	Nitrogen (t km^{-2})	Pesticide (t km^{-2})
EU-15	6.0	0.23
OECD	2.2	0.07
HU	5.8	0.17
Countries characterised by higher rates of chemical use		
BE	10.6	0.69
NL	13.4	0.41
DE	10.5	0.17
Countries characterised by median rates of chemical use		
CZ	6.8	0.10
DK	7.4	0.11
UK	5.9	0.19
FR	7.5	0.28
IE	8.1	0.05
PL	6.3	0.07

Source: Source: OECD (2008)

The estimations were made for crop production and mixed farms according to countries and groups on the basis of different levels of agrochemical use. Thus the above questions were separately examined for the EU-25, Hungary, the group of Belgium, the Netherlands and Germany (high levels of agrochemical use), as well as the group of the Czech Republic, Denmark, the United Kingdom, France, Ireland and Poland (Table 1). The estimation model of cost savings was:

$$C_{n,m} = p_m \cdot \sum_{k=1}^{c} \sum_{j=1}^{b} \sum_{i=1}^{a} h_{i,j,k}^{y} \cdot \overline{c}_{n,m,i,j,k}^{y}$$

where:

$C_{n,m}$: total savings of n cost type in m model variant at EU and country group level [EUR];

p_m: average degree of n cost type savings in m model variant, Pesticide cost savings: p_1=25%, p_2=35%, p_3=50% [%];

m: serial number of model variant;

n: cost type (*1*= pesticide cost);

i: economic size unit category in FADN database, $i \in$[1,a], a=max(6); examined economic size unit categories: 16-40 ESU, 40-100 ESU, (4) 16 - <40 ESU, (5) 40 - <100 ESU, (6) >= 100 ESU;

j: type of activity in FADN database, $j \in$[1,b], b=max(8); examined types of activity: (1) Field crops, (8) Mixed;

k: member countries of the EU, $k \in$[1,c], c=25 (2006), c=27 (2009);

y: reference year of data in FADN database, $y \in$[1989,2009]; examined years: 2006, 2009;

$h_{i,j,k}^{y}$: number of represented farms in FADN database in y year, in i economic size unit category, in j type of activity, in k member country [holdings];

$\overline{c}_{n,m,i,j,k}^{y}$: average value of n type of cost in FADN database in y year, in i economic size unit category, in j type of activity, in k member country [EUR/holdings];

Survey of Hungarian farmers

In the spring and summer of 2011, 72 crop producer farmers attending agricultural shows at Gödöllő (n=25), Agárd (n=14), Siófok (n=20) and other places (n=13) took part in a structured interview survey designed to explore the extent and awareness of precision crop production. The questions asked concerned the features of farms (size, type and machinery), the elements of precision crop production applied, and the circumstances and reasons of their introduction. Farmers could choose from the following precision farming technology elements: row tracking, soil sampling with GPS, precision fertilising (on-line or off-line), precision weed management (on-line or off-line), precision plant protection (on-line and off-line), precision sowing, yield mapping etc. Farmers who so far have rejected precision crop production were asked why this is and under what conditions would they consider converting.

The sample included farmers from all NUTS2 regions of Hungary, namely West Transdanubia (10%), Central Trandanubia (30%), South Trandanubia (8%), Central Hungary (13%), North Hungary (11%), North Great Plain (18%) and South Great Plain (10%). In terms of farm size, 25% were under 4 ESU, 13% were between 4 and 8 ESU, 33% were between 8 and 16, and 30% were over 16 ESU. The average age of respondents was 48 years.

Cramer V tests were used to determine if the age of the farmer and the amount of cultivated land were correlated with the uptake of precision crop production. The significant difference level was five per cent.

Results

Macroeconomic and environmental benefits of precision plant protection

At the EU-25 level, depending on the percentage of pesticide savings achieved, the estimated amount of pesticide savings is 5.7-11.4 thousand tonnes if 15 per cent of the farms convert to precision plant protection, 9.5-13.1 thousand tonnes if 25 per cent convert, while in the best case scenario, the savings can be between 15.2 and 30.4 thousand tonnes (Table 2).

Table 2: Expected savings in pesticide use owing to the introduction of precision plant protection (EU-25).

			Farms converting to precision plant protection (%)		
			15	25	40
16-100 ESU	Converted area (000 ha)		5,334	8,887	14,219
	Pesticide savings (t)	25%	2,925	3,574	7,799
		30%	4,095	3,950	10,919
		50%	5,849	4,900	15,598
>100 ESU	Converted area (000 ha)		5,624	9,373	14,997
	Pesticide savings (t)	25%	2,771	4,618	7,389
		30%	4,095	6,465	10,344
		50%	8,190	9,235	14,777
Total	Converted area (000 ha)		10,956	18,260	29,216
	Total pesticide savings (t)	25%	5,695	8,192	15,188
		30%	8,190	10,415	21,263
		50%	11,391	14,135	30,375

Note: Assuming 2.4 kg ha^{-1} pesticide use (EU-25; OECD database)
Source: own calculations based on EUROSTAT data from 2009

Table 3: Estimated pesticide cost savings by crop producing and mixed farms converting to precision plant protection in the EU-25 and selected groups of European countries (million EUR).

Country group	Farm group 16–100 ESU Median savings				Farm group 100 ESU Median savings			
	25%	30%	50%	Percent (%)	25%	30%	50%	Percent (%)
EU-25	854.1	1,195.7	1,708.1	100.0	820.0	1,148.0	1,640.0	100.0
HU	24.6	34.4	49.1	2.9	22.0	30.9	44.1	2.7
BE+NL+DE	221.9	310.7	443.8	26.0	232.5	325.5	465.0	28.4
CZ+DE+UK+FR+IE+PL	487.8	683.0	975.7	57.1	472.5	661.5	945.0	57.6

Source: own calculations based on FADN data from 2009

Assuming constant yield, owing to the site-specific treatment, the realised savings in pesticide active ingredients can be 8-10 per cent of the amount used previously. At the same time, at the farm level, the savings will also reduce the material costs, as well as the competitiveness of the farm and its role in reducing the environmental burden.

The total production cost for farms in the EU-25 above 16 ESU amounted to EUR 30,479 million in 2009. The total pesticide costs reached 18.7 per cent of this. Considering the possible scenarios of shifting to precision crop production, and assuming the above prevalence on pesticide costs, between EUR 1,674.1 and EUR 3,348.1 million of savings can be achieved at the EU-25 level due to the adoption of precision pest control (Table 3).

Between 0.6 and 6.2 per cent of savings in farm-level production costs can be attributed to the precision use of pesticides. The total pesticide costs are 14.8 per cent of the total costs in the group of countries (BE+NL+DE) that use more agrochemicals. The savings on production costs can be between EUR 5.590 and EUR 57.770 million, which can dramatically improve the competitiveness of the sector.

The results from macro-level models support the fact that precision plant protection can have an important role in environmental burden reduction, alongside other elements of technological development in agriculture.

By proving the first hypothesis (H1), we can state that by promoting the switch to precision technology the greening objectives of the CAP can be reached.

Uptake of precision crop production: what is it like?

Thirty-one of the interviewed farmers reported that they used use precision farming technology and 41 stated that they did not. Most farmers use only one element of precision farming technology. Row tracking was the most frequently applied technique (35.5 per cent), then net-like soil sampling (22.6 per cent), followed by precision fertilisation (19.4 per cent) and precision crop protection (16.1 per cent) and precision soil cultivation (9.7 per cent). The other elements were mentioned only by one farmer in the survey (Table 4).

The cross-correlation examined the effects of the most important farm parameters (amount of cultivated land, income, age of farmers, education) on the adoption of precision farming technology. There was a moderate but significant positive correlation between the area of cultivated land and the adoption of precision farming technology (Cramer V=0.36 α=0.01). With the age of the farmers adopting precision crop production there was a also moderate, positive correlation (Cramer V=0.31 α=0.03). The farmers using more elements of precision technology come from the middle-aged category (40-65 years), while none of the older farmers (over 65 years old) applied precision technology. While these results are based on a relatively small sample size, they agree with those of Kutter *et al.* (2011). There were no significant correlations between the income of farms, the highest education level of farmers and the adoption of precision farming technology.

Among the changes expected from the implementation of precision farming, the reduction of environmental burden from crop production was mentioned most frequently by the interviewees, followed by the additional income, the size of which was estimated to be between 5 and 15 per cent by 63 per cent of the respondents. The reduction in agrochemical use was the third most frequently mentioned consequence. On the basis of cross-table analysis there was a positive, medium strength relationship (ϕ = 0.25, five per cent significance level) between the implementation of precision crop production and the estimation of changes in incomes. The reasons given for the low uptake of the technology included the low awareness level, the negative approach of management and the positive correlation (ϕ =0.35) with the increase of the farm area.

From among the reasons given in the survey for the slow uptake of precision technology we were able to prove the first part of our second hypothesis (H2), namely that the higher scale of farming can enhance the expansion of precision crop production.

Table 4: Frequency of use of elements of precision farming amongst Hungarian farmers in 2011.

Element of precision technology	Farms applying an element of precision technology (%)		Median proportion of farm area using precision farming technology (%)
	of total sample (n=72)	of farms using of precision technology only (n=31)	
Row tracking	15.3	35.5	100
Net-like soil sampling	9.7	22.6	58
Precision fertilising	8.3	19.4	76
Precision crop protection	6.9	16.1	71
Precision soil cultivation	4.2	9.7	75
Yield mapping	1.4	3.2	100
Aerial remote sensing	1.4	3.2	100
Precision weed control	1.4	3.2	n.d.
Precision sowing	1.4	3.2	100
Remote sensors	-	-	-
Weed mapping	15.3	35.5	100

Source: own survey using structured interviews

Discussion

The expansion of precision crop production is still in its early phase. The process can be characterised from the uptake point of view of innovation, based on Rogers (1962); our typology for the uptake is as follows:

1. During its introduction precision crop production had a relative advantage compared to the general technologies used in crop cultivation, which would have allowed for relatively rapid growth;
2. In terms of compatibility, precision farming can be considered less compatible. This is due to the fact that farmers are characterised by different levels of knowledge and skills, by a mistrust in the new technology and by their different farm sizes and financial opportunities. If support from consultants for the introduction of the new technology is missing, the uptake process will be slow;
3. The application of precision crop production is not easy to understand, it requires much attention, precise work and a wide range of information;
4. Relevant industry players and suppliers affected in the application and marketing of the technology are dominant with regards to the application and cognition;
5. With the introduction of precision technology some of the available benefits are directly observable, such as material savings, improvements in cost-effectiveness, together with the additional costs and expenses. The indirect effects, however, such as reduction of environmental burden and improvements in food safety, are less evident. While the measurable positive returns remain unclear to the farmer, and the risks remain high, even in the presence of a good financial background, the spread of the technology is slow.

The adoption of more elements of precision plant production technology is slow across the world (Godwin *et al*., 2003; Pecze, 2006; Griffin and Lowenberg-DeBoer, 2008; Pedersen *et al*., 2010; Lencsés, 2012). The results of our survey suggest that the slow uptake of some elements of the technology can be partly explained by the problematic questions of shifting, which state that the role of expertise and precision will increase in the converted farms, the documentation and tracking of the procedures that will be required and not all the actors will view this positively, the production costs will often be higher and the returns on extra investment are not always ensured. In these cases all kinds of cooperation and strategic collaborations among the farmers, extension services and providers are important in the adoption of new technology, such as the forms of joint machine use (e.g. machinery rings). The significance of relational capital as the basis of knowledge based growth is greater within small and medium-size enterprises' innovational cooperation (Takács, 2000; Husti, 2009; Welbourne and Pardo-del-Val, 2009; Macieczjak, 2012; Vuylsteke and Van Gijseghem, 2012). It is important to highlight the role of these forms of cooperation because the individuals make their decisions on the adoption of new technologies on the basis of information coming through these channels (Csizmadia, 2009).

The benefit of the transition to precision pest management is proven, since spot treatments will result in real savings in the use of plant protection materials, depending on the area infected by pests. In all cases where there is heterogeneity within the field, and a high number of those spots, plant protection treatments can be omitted without suffering significant economic damage. The model calculations underlying this showed that precision crop protection can result in significant savings in agrochemical use at the macroeconomic level. Similar positive economic and social results in Danish farms were reported by Jensen *et al*. (2012) through an increase in the farmers' income and reductions in fuel consumption and pesticide use. As regards to agrochemical use, after shifting to precision crop production in the EU-25 countries, presuming an optimistic scenario and in the case of the reasonable use of the currently applied substances, 30 thousand tonnes less pesticide would be required for the currently produced yield. If the proportion of converted farms is around 30-60 per cent, the 10-35 per cent reduction in substance use compared to the intensive, entire surface treatment technology would reduce the environmental burden to a similar degree at the national economy level. In this case individual utility and social utility coincide. The yield uncertainty can be reduced during the production of food and industrial raw materials, as it helps traceability in food chains and improves the predictability both at farm and national level.

Precision crop production, as an environmentally friendly farming practice, can be one of the means of enhancing the green component of Pillar 1 of the CAP proposed for the period 2014-2020. The greening impact, i.e. the decreasing substance use measured in agrochemicals, can be greater than the savings reached by leaving the land fallow, because this practice prefers marginal areas where agrochemical use is originally lower. Farmers who leave their land fallow perform more intensive production on their other land in order to compensate for the yield losses. This process occurred within the United States agriculture before the turn of the millennium (Knutson, 1993). We agree with those who call attention to alternative solutions in the discussions of the CAP proposals and do not exclude the acceptance of innovation outputs (technique, technology and organisation) in the CAP system (Groupe de Bruges, 2012).

To force and promote the uptake of precision farming one tool can be – as a new element, an indirect assistance – putting the application of precision technology into the tools of the CAP greening component.

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