MM10: Precision Agriculture in Crop Production

Category

Cropland and grassland management: nutrient management

Overview

Precision agriculture technologies (PATs) for crop production entail using digital technologies to measure and respond to inter- and intra-field variability in crop needs. PATs allow the farmers to consider the field as a heterogeneous entity and apply selective management, potentially increasing efficiency (Aubert *et al.* 2012). Schwartz *et al.* (2010) categorised PATs into guidance, recording and reacting technologies. Guidance technologies (e.g. controlled traffic farming, machine guidance) help to make machinery movement more precise within and between the fields. Recording technologies (e.g. soil mapping, canopy sensing) collect information from the field (including the soil and crops) before, during or after the growing period. Recorded data, in turn, are used by reacting technologies, which include hardware and software, (e.g. variable rate irrigation, variable rate pesticide application) making decisions on and carrying out input applications at the field (Balafoutis *et al.* 2017). Precision technologies can take into account not only in-field variation, but the temporal aspect if in-season information is collected (Diacono *et al.* 2013). The technology is rapidly developing, covering an increasing number of management areas; under the H2020 EU research funding scheme there have been over a dozen projects in recent years working on technological and infrastructure development for precision solutions across farming systems[1].

PATs in crop production can reduce GHG emissions and GHG emission intensity as they result in high or equal yield while using less input. The five main ways they can affect GHG emissions are summarised by Balafoutis *et al.* (2017): increasing yield with while reducing N fertiliser application, reducing tillage and thus increasing soil C sequestration, reducing fuel consumption and reducing other inputs to field operations (impacting off-farm emissions). Using additional precision technologies, like variable rate seeding and separation by grain quality (e.g. via on-the-go systems (Taylor and Whelan 2007) or zone harvesting (Skerritt *et al.* 2002)) can further enhance gross margin and/or nitrogen use efficiency maximisation of the fields.

As the complexity of possible system specifications is large, and evidence on the environmental performance of the various systems is sparse, only one combination of technologies is selected for further evaluation: machine guidance (MG) with variable rate nitrogen application (VRNT). VRNT systems can be useful both for crop and grass production (Berry *et al.* 2017).

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[1] https://cordis.europa.eu/article/id/400295-precision-farming-sowing-the-seeds-of-a-new-agricultural-revolution/en

Mitigation summary

Table 1 Effects on emissions

GHG categories	Effect*	Notes
Enteric CH_4		
Manure CH_4		
Manure N_2O		
Soil N_2O: applied N	-	
Soil N_2O: grazing		
Energy CO_2: fieldwork	-	
Energy CO_2: other		
CO_2 liming and urea		
CO_2 sequestration below ground		
CO_2 sequestration above ground		
Pre-farm emissions	-	N fertiliser production
Post-farm emissions		
Substitution of higher C products		
Production increases by more than the emissions	Yes	
	Rating	
Confidence in mitigation effect	Medium	
Cost-effectiveness**	Moderate	
Confidence in cost-effectiveness	Medium	

* ”-“ GHG reduction, “+”: GHG increase, “ ”: no significant effect
** low: =< £0/tCO_2e, moderate: £0/tCO_2e< >SCC, high: >SCC

Related measures and potential synergies

Table 2 Likely effects on the abatement potential of other measures

Measure	Impact
	-
	-

Inclusion in other marginal abatement cost curves

Table 3 Past assessment of the measure

UK 2008	UK 2010	UK 2015	Ireland 2012	France 2013	France 2019
No	No	Yes	No	No	?

What does the measure entail?

The measure would require farmers to use MG as well as VRNT for their arable and temporary grassland field operations, either buying the system, or using contractors for fieldwork who use these technologies.

MG technologies are systems that pilot machinery using GPS in order to reduce overlaps and avoid gaps of passes. At the entry level a GPS receiver mounted on the machinery and a lightbar or an on-board display providing driving direction is needed; with such systems ±40 cm accuracy can be achieved. More advanced solutions, with accuracy up to ±2 cm, use auto-guidance systems (auto-steering) integrated in the tractor's hydraulics and directly controlling steering. MG is a prerequisite for VRNT, but could be used in itself (Barnes *et al.* 2017a).

Figure 1 Example of a VRNT system (Stamatiadis et al. 2018)

VRNT enable adjusting the application rate to match fertiliser need better in that precise location within the field. Using a digital map or real-time sensors, a decision tool calculates the N needs of the plants and transfers that information to a controller, which adjusts the spreading rate (Barnes *et al.* 2017a).

In line with our previous estimates (Eory *et al.* 2015), we assumed the implementation of a medium accuracy system, capable of 10 cm accuracy auto-steering and including yield mapping and variable rate nitrogen application.

Abatement rate

Experimental evidence on the N fertiliser use and yield effect shows a large variation, between -57% and +1% and -2% to 10%, respectively. Barnes *et al.* (2017b) found that most potato and wheat farmers in the UK perceived a -5% - +5% effect of the technology on N fertiliser and fuel use, and a 5-10% increase in wheat yield.

Table 4 Data from literature on abatement

Abatement	Value	Country	Reference
N fertiliser use Yield Fuel use	As perceived by the farmer, wheat -5 - -10% +5 - +10% -5% - +5%	Belgium	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, potato -5% - +5% +5 - +10% -5% - +5%	Belgium	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, wheat -11 - -20% +5 - +10% -5% - +5%	Greece	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, cotton -11 - -20% +5 - +10% -5% - +5%	Greece	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, wheat -5% - +5% +5 - +10% -5% - +5%	UK	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, potato -5% - +5% -5% - +5% -5% - +5%	UK	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, wheat -5% - +5% -5% - +5% -5% - +5%	Germany	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, potato -5 - -10% -5% - +5% -5% - +5%	Germany	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, wheat -5 - -10% -5% - +5% -5% - +5%	The Netherlands	(Barnes *et al.* 2017b)
N fertiliser use Yield Fuel use	As perceived by the farmer, potato -5 - -10% -5% - +5% -5 - -10%	The Netherlands	(Barnes *et al.* 2017b)
N fertiliser use	-37%; 100%: 217 kg N ha^{-1} (winter wheat) (no significant difference in yield quantity) Experimental	Greece	(Stamatiadis *et al.* 2018)
N fertiliser use	-57% (forage maize) Experimental	UK	(Mantovani et al 2011)

Abatement	Value	Country	Reference
N fertiliser use	+1%; 100%: 175 kg N ha^{-1} (winter wheat) (no significant difference in yield quantity or in N efficiency) and -2.5%; 100%: 200 kg N ha^{-1} (winter wheat) (no significant difference in yield quantity or in N efficiency) Experimental	Germany	(Link *et al.* 2008)
N fertiliser use Yield N fertiliser use Yield N fertiliser use Yield	(winter wheat) -9%; 100%: 53 kg N ha^{-1} and +4.4%; 100%: 2.47 t ha^{-1} -12%; 100%: 65 kg N ha^{-1} and -2.2%; 100%: 8.25 t ha^{-1} -12%; 100%: 68 kg N ha^{-1} and +2.6%; 7.15 t ha^{-1} Experimental	Germany	(Ehlert *et al.* 2004)
N fertiliser use	0 - -46%; 100%: 134.7 kg N ha^{-1} (winter wheat) (no significant difference in yield quantity) Experimental	US	(Flowers *et al.* 2004)
Yield	+0.3 ha^{-1} (winter barley) Experimental	UK	(Welsh *et al.* 2003a)
Yield	0 - +0.46 t ha^{-1} (winter and spring wheat) Experimental	UK	(Welsh *et al.* 2003b)

Cost

The major financial impact of the measure is the capital and running cost of the equipment along with the subscription costs to data providers (e.g. satellite data) and software tools. Positive effect on the gross margin can be expected from the change in fertiliser and fuel use, yield quantity and quality. Further gross margin impacts can include a change labour requirement.

The cost calculations are based on assuming an average farm size of 120 ha, and the capital costs not being inversely proportional to the farm size as variable rate N fertilisation can be done by contractors.

Table 5 Financial costs and benefits of the measure

Costs/savings	Value ('-' sign for savings)	Notes
Cost of hired labour	Mostly -5% - +5% (-5 - -10% for Dutch potato farmers)	Potato, wheat and cotton farmers in Belgium, Greece, Germany, the Netherlands (Barnes *et al.* 2017b)
Labour training time	-5% - +20%	Potato, wheat and cotton farmers in Belgium, Greece, Germany, the Netherlands (Barnes *et al.* 2017b)
Management time	Mostly -5% - +5% (+5 - +10% for Belgian wheat farmers)	Potato, wheat and cotton farmers in Belgium, Greece, Germany, the Netherlands (Barnes *et al.* 2017b)

Costs/savings	Value ('-' sign for savings)	Notes
Time spent on field	-10% - +10%	Potato, wheat and cotton farmers in Belgium, Greece, Germany, the Netherlands (Barnes *et al.* 2017b)
Cost of hired labour	-5% - +5%	Potato farmers, UK (Barnes *et al.* 2017b)
Labour training time	-5% - +5%	Potato farmers, UK (Barnes *et al.* 2017b)
Management time	-5% - +5%	Potato farmers, UK (Barnes *et al.* 2017b)
Time spent on field	-5% - +5%	Potato farmers, UK (Barnes *et al.* 2017b)
Cost of hired labour	-5% - +5%	Wheat farmers, UK (Barnes *et al.* 2017b)
Labour training time	-5% - +5%	Wheat farmers, UK (Barnes *et al.* 2017b)
Management time	+5 - +10%	Wheat farmers, UK (Barnes *et al.* 2017b)
Time spent on field	-5% - +5%	Wheat farmers, UK (Barnes *et al.* 2017b)
All cost	Advanced system: £12,000 capital cost and 3% annual maintenance, signal cost: £750 y^{-1}, yield monitor cost: £250 y^{-1}, 3% reduction in overlaps (and thus in variable costs)	(Eory *et al.* 2015)
Equipment and monitoring cost	Basic system (with auto-steering): £48,000 $farm^{-1}$, i.e. £16 ha^{-1} y^{-1} (500 ha farm), £4 ha^{-1} y^{-1} (2000 ha farm) Advanced system: £119,000 $farm^{-1}$ + £8 ha^{-1} y^{-1}, i.e. £37 ha^{-1} y^{-1} (500 ha farm), £14 ha^{-1} y^{-1} (2000 ha farm)	Australia (Jochinke *et al.* 2007)
Equipment and monitoring cost	Basic system (with auto-steering): £3,500 $farm^{-1}$, i.e. £1 ha^{-1} y^{-1} (500 ha farm), £0.2 ha^{-1} y^{-1} (2000 ha farm) Medium system: £19,000 $farm^{-1}$, i.e. £7 ha^{-1} y^{-1} (500 ha farm), £2 ha^{-1} y^{-1} (2000 ha farm) Advanced system: £43,000 $farm^{-1}$, i.e. £16 ha^{-1} y^{-1} (500 ha farm), £4 ha^{-1} y^{-1} (2000 ha farm)	Australia (Robertson *et al.* 2007)

Costs/savings	Value ('-' sign for savings)	Notes
Cost of data and software	Veris soil scanning: £6.00 ha^{-1} Nutrient samples: £2.20 ha^{-1} 2 drone flights: £6.00 ha^{-1} Yield mapping: £3.50 ha^{-1} Weather/soil moisture station: £7.50 ha^{-1} Software: £2.50 ha^{-1}	Future Farming[2], 2019

Applicability

Technically the measure is applicable on all cropland and grassland.

Current uptake and maximum additional future uptake

A recent study conducted in five Baltic states found precision farming (without specification of VRNT) adoption rates (approximated from investment made in the last 10 years) between 9-21% (Finland: 9%, Poland: 10%, Sweden: 14%, Denmark: 19%, Estonia: 21%) (Konrad *et al.* 2019).

Current uptake of precision farming in the UK can be estimated from the 2012 Farm Practices Survey on Current Farming Issues (Defra 2013), which found that in England 2-22% of farms use precision farming technologies and 16% use variable rate application, though only 11% uses yield mapping (25% cereal farms, 18% other crop farms, 5% pig/poultry and dairy farms, 2% grazing livestock farms, 11% mixed farms). The implementation rates are higher for cereal and cropping farms, lower for dairy and mixed farms and lowest for pigs and poultry and cattle farms. The rates increase with farm size. With expected advances in the technology and concurrent reduction in costs we expect that the uptake by 2050 would be 50% on arable and 20% on improved grassland without specific policy support.

Assumptions used in the MACC

Parameter	Change in value	Notes
N application rate	-5%	
Fuel use	-3%	(Eory *et al.* 2015)
Yield	+7.5%[1,2]	
Mobile machinery energy use	942-3,230 kWh ha^{-1} y^{-1}	(Warwick HRI and FEC Services 2007)
Fuel conversion factor (diesel (average biofuel blend), net CV)	0.26023 kg CO_2e kWh^{-1}	(BEIS 2019)
Auto-steer (±10 cm)	£5,000 in every 5 years	(Eory *et al.* 2015)

[2] https://www.futurefarming.com/Tools-data/Articles/2017/9/Precision-farming-trial-to-reveal-true-cost-of-technology-1582WP/

Parameter	Change in value	Notes
Yield monitor	£5,000 in every 15 years	(Eory *et al.* 2015)
Maintenance cost	5% of capital cost per year	(Eory *et al.* 2015)
Signal and data costs	£500 y^{-1}	(Eory *et al.* 2015)
Training	£500 in every 15 years	(Eory *et al.* 2015)
Variable costs (including fuel)	-3%	(Eory *et al.* 2015)
Estimated 2050 uptake	50% cereal, 40% other non-grass crops, 20% improved grass	

[1] The potential effects of grass yield increase on livestock production are not included, the additional grass is assumed to be sold

[2] Includes increase in crop residue N

Wider effects

Table 6 Wider effects of the measure

Aspect	Effect	Reference
Positive effects		
Off-farm GHG	Reduced emissions from fertiliser production	
Production		
Adaptation		
Environment	Reduced nitrate leaching and ammonia emissions	
Negative effects		
Off-farm GHG		
Production		
Adaptation		
Environment		

Identified implementation challenges and barriers

Table 7 Potential barriers of the measure

Barrier to uptake	Reference
Low confidence in yield increase and cost reduction, high costs, not enough support for training, not enough technical support from sales people, low level of trust in technology	(Barnes *et al.* 2017b, Barnes *et al.* 2019)
Other key risks/uncertainties	**Reference**

References

Aubert, B. A., Schroeder, A. and Grimaudo, J. (2012) IT as enabler of sustainable farming: An empirical analysis of farmers' adoption decision of precision agriculture technology. Decision Support Systems 54, 510-520.

Balafoutis, A., Beck, B., Fountas, S., Vangeyte, J., van der Wal, T., Soto, I., Gomez-Barbero, M., Barnes, A. and Eory, V. (2017) Precision agriculture technologies positively contributing to GHG emissions mitigation, farm productivity and economics. Sustainability 9, 1339.

Barnes, A., Eory, V. and Sinclair, R. (2017a) Deliverable 4: Pilot Survey Results and Final Questionnaire, Report No Deliverable 4 in the study called "The contribution of Precision Agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU", with reference JRC/SVQ/2015/J.4/0018/OC.

Barnes, A., Eory, V. and Sinclair, R. (2017b) Deliverable 5: Survey Results, Report No Deliverable 5 in the study called "The contribution of Precision Agriculture technologies to farm productivity and the mitigation of greenhouse gas emissions in the EU", with reference JRC/SVQ/2015/J.4/0018/OC.

Barnes, A., De Soto, I., Eory, V., Beck, B., Balafoutis, A., S+ínchez, B., Vangeyte, J. +., Fountas, S., van der Wal, T. and G+¦mez-Barbero, M. (2019) Influencing factors and incentives on the intention to adopt precision agricultural technologies within arable farming systems. Environmental Science & Policy 93, 66-74.

BEIS (2019) Greenhouse gas reporting: conversion factors 2019.

Berry, P. M., Holmes, H. F. and Blacker, C. (2017) Development of methods for remotely sensing grass growth to enable precision application of nitrogen fertilizer. 2017/06/01, 758-763.

Defra (2013) Farm practices survey October 2012 - Current farming issues, Defra.

Diacono, M., Rubino, P. and Montemurro, F. (2013) Precision nitrogen management of wheat. A review. Agron. Sustain. Dev. 33, 219-241.

Ehlert, D., Schmerler, J. and Voelker, U. (2004) Variable rate nitrogen fertilisation of winter wheat based on a crop density sensor. Precision Agriculture 5, 263-273.

Eory, V., MacLeod, M., Topp, C. F. E., Rees, R. M., Webb, J., McVittie, A., Wall, E., Brothwick, F., Watson, C., Waterhouse, A., Wiltshire, J., Bell, H., Moran, D. and Dewhurst, R. J. (2015) Review and update of the UK agriculture MACC to assess the abatement potential for the 5th carbon budget period and to 2050, the Committee on Climate Change.

Flowers, M., Weisz, R., Heiniger, R., Osmond, D. and Crozier, C. (2004) In-Season Optimization and Site-Specific Nitrogen Management for Soft Red Winter Wheat. Agronomy Journal 96.

Jochinke, D. C., Noonon, B. J., Wachsmann, N. G. and Norton, R. M. (2007) The adoption of precision agriculture in an Australian broadacre cropping system - Challenges and opportunities. Field Crops Research 104, 68-76.

Konrad, M. T., Nielsen, H. Ø., Pedersen, A. B. and Elofsson, K. (2019) Drivers of farmers' investments in nutrient abatement technologies in five Baltic Sea countries. Ecological Economics 159, 91-100.

Link, J., Batchelor, W. D., Graeff, S. and Wilhelm, C. (2008) Evaluation of current and model-based site-specific nitrogen applications on wheat (Triticum aestivum L.) yield and environmental quality. Precision Agriculture 9, 251-267.

Mantovani, E. C., Misiewicz, P., White, D. and Godwin, R. J. (2011) Results of preliminary study of spatially variable Nitrogen application rates for forage maize in the UK. LANDWARDS EVENTS 2011: High technology for Agriculture – The next phase. A series of Forward Looking Events from IAgrE,

Robertson, M., Carberry, P. and Brennan, L. (2007) The economic benefits of precision agriculture: case studies from Australian grain farms, CSIRO, Grains Research and Development Corporation.

Schwartz, J., Herold, L. and Polling, B. (2010) Typology of PF technologies, Report No FutureFarm FP7 Project Deliverable 7.1.

Skerritt, J. H., Adams, M. L., Cook, S. E. and Naglis, G. (2002) Within-field variation in wheat quality: implications for precision agricultural management. Aust. J. Agric. Res. 53, 1229-1242.

Stamatiadis, S., Schepers, J. S., Evangelou, E., Tsadilas, C., Glampedakis, A., Glampedakis, M., Dercas, N., Spyropoulos, N., Dalezios, N. R. and Eskridge, K. (2018) Variable-rate nitrogen fertilization of winter wheat under high spatial resolution. Precision Agriculture 19, 570-587.

Taylor, J. and Whelan, B. (2007) On-the-go grain quality monitoring: A review. 4th International Symposium on Precision Agriculture (SIAP07), At Vicosa, Brazil, 4th International Symposium on Precision Agriculture (SIAP07), At Vicosa, Brazil,

Warwick HRI and FEC Services (2007) Direct energy use in agriculture: opportunities for reducing fossil fuel inputs, Report No Defra AC0401, Defra.

Welsh, J. P., Wood, G. A., Godwin, R. J., Taylor, J. C., Earl, R., Blackmore, S. and Knight, S. M. (2003a) Developing strategies for spatially variable nitrogen application in cereals, part I: Winter barley. Biosystems Engineering 84, 481-494.

Welsh, J. P., Wood, G. A., Godwin, R. J., Taylor, J. C., Earl, R., Blackmore, S. and Knight, S. M. (2003b) Developing strategies for spatially variable nitrogen application in cereals, part II: Wheat. Biosystems Engineering 84, 495-511.