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Advice on the inclusion of precision farming in RPP2

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ClimateXChange produced this brief early in the preparation of the second Report on Proposals and Policies. Its purpose was to help frame questions and lines of enquiry and as a result, did not fully take account of real-world constraints (economic, political, social, institutional) that mean that these theoretical abatement levels are unlikely to be achievable in practice. ClimateXChange produced these reports in early 2012, and some of the figures presented may have since been updated.

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1. Background

The Rural and Environment Science and Analytical Services Division of Scottish Government has requested ClimateXChange to provide further advice on the greenhouse gas (GHG) abatement potential and cost of precision farming (PF), following up a report in February 2012 (Eory & Moran 2012). Building on the scarce evidence presented in scientific papers, reports and also relying on expert opinion, this report discusses the likely implications of precision farming techniques on GHG mitigation and farm finances, and the likely future uptake of this measure. The report emphasises that current knowledge is limited and does not allow us to make robust estimates of the impact of PF on emissions.

2. Key points

- PF includes a wide range of technologies, and is effective where intra-field variability in yield is high.
- Its GHG effects of are not well-explored. A rough abatement rate estimate of 0.2 t CO_2e ha^{-1} is used in this report.
- Applicability of the measure is estimated at 20-40% on all croplands and grasslands (excluding rough grazing) – though more research is needed to verify this assumption.
- These translate to an abatement potential of 85 kt CO_2e in Scotland, assuming 100% uptake of the measure.
- PF will reduce the abatement potential of the other GHG measures targeting N use.
- Capital investments are in a range of £4,500 to £18,000, with maintenance cost estimated at 3.5-8%. Sampling costs can be around £7-£40 ha^{-1}. A rough estimate of financial benefits (due to increased yield and reduced fertiliser) is £22 ha^{-1}.
- By 2022, PF techniques could be profitable on farms bigger than 100 ha, as future trends in crop, fertiliser and technology prices favour PF. This corresponds to roughly half of the non-LFA farmed area in Scotland.
- As a conservative estimate, we suggest 20% as a 2022 uptake assumption.
- Total abatement potential with 20% uptake is estimated to be 17 kt CO_2e, noting that the applicability rates and the uptake might be underestimated.

3. A short introduction to precision farming technology

Precision farming is a relatively new management practice made possible by the development of information technology and remote sensing. This term encompasses many technologies providing more precise information about the managed resources and at the same time allowing the farmer to respond to in-field variations by allocating inputs, such as fertiliser, tillage and irrigation in a differentiated manner, rather than indiscriminate field-level operations which result in sub-optimal efficiency.

PF can be beneficial on fields where yield varies according to a predictable pattern due to differences in soil quality, weed infestation, drainage, etc. While yield variability is generally caused by these factors, equipment or operator error (e.g. planter problems or faulty nozzles on applicators) can also be a reason and explored by PF techniques (Rains & Thomas 2009). PF also provides an opportunity to reduce physical overlap between machinery passes. The financial benefits of PF are reduced resource use, higher yields and less fuel use, while the environmental benefits are reduced GHG emissions and reduced diffuse water pollution from fertilisers, agrochemicals and fuel.

If a field shows intra-field variance, the proportion of the area within the field which would benefit from differentiated management can be assessed, e.g. the areas showing higher or lower shoot density compared to the average (or targeted) density require the application of variable rate technology (see below). This proved to be 12-52% in a five-year experiment described by Godwin et al. (Godwin *et al.* 2003a, Godwin *et al.* 2003b). Data provided in the current report correspond to the whole field, including both the average and the non-average areas within the field.

The five main groups of technologies used in PF – as described in (Rains & Thomas 2009) – are:

- Geographical Information Systems (GIS) are software to manage spatial data.
- Global Positioning Systems (GPS) provides the topographic information of the positions used in GIS, though for in-field accuracy (3-5 feet) differential GPS (DGPS) is needed.
- Sensors make measurements on soil properties, pests, crop health, etc. in order to vary management operations accordingly. They are either placed on the field and their signals picked up by hand-held devices or devices placed on tractors, or belong to remote sensors, which make aerial or satellite photographs.
- Yield Monitoring (YM) is measuring the crop yield during harvest, providing a yield map with information on production and variability.
- Variable Rate Technology (VRT) includes computer controllers and associated hardware to vary the output of fertilizer, lime, and pesticide, of which fertiliser application is the most developed.

In general, the level of spatial precision is ±40cm to ±2cm, requiring higher investments for the more precise systems. The most basic equipment allows for reduced machinery passes by visual aids to the driver (GPS + GIS technologies), while at more cost autosteering options are also available, which are essential for VRTs (Rees, R., pers. comm.).

Farmers already using PF technology mostly gather information by yield monitoring and soil sampling, with some of them relying on soil conductivity mapping as well, while their PF operations mainly include VRT fertilisation, some of them also doing VRT seeding, VRT herbicide/pesticide and VRT lime applications (Pedersen *et al.* 2001, Reichardt *et al.* 2009, Robertson *et al.* 2012).

Though the main focus of the developments has been on crop production, PF technologies can be applied to grasslands as well. At the moment, the applicability on grasslands is restricted by the availability of technologies providing data on grasslands' status: soil sampling would be too expensive due to the size of grasslands, while remote sensors working well with monoculture have to be further developed to assess mixed swards (Rees, R., pers. comm.).

4. Characteristics of precision farming

4.1. Earlier assumptions

The "RPP2 Possibilities" report (Eory & Moran 2012) concluded that assuming 81% uptake in 2027, the additional abatement potential by PF might be 115 kt CO_2e, achieved by increasing the abatement rate by 0.2 t CO_2e ha^{-1} of the measure "Improved timing of mineral nitrogen (N) application".

Here, we suggest including PF as a separate, stand-alone mitigation measure in the GHG abatement calculations, allowing a more transparent characterisation of its costs and benefits. Its effects on other measures targeting N management should be included by introducing interaction factors (IFs) for PF.

4.2. Abatement potential and interactions

The GHG abatement rate achievable with PF was estimated at 0.2 t CO_2e ha^{-1} by Moran et al. (2008). Generally, this abatement is achieved through saving in N application rates. A 20% saving is a realistic assumption, translating to a 20% reduction in N_2O, which is in the order of 0.1-0.2 t CO_2e (Rees, R., pers. comm.). As PF technology allows for better targeting plant nutrient needs, the N efficiency of the farm improves and its nitrous oxide emissions are reduced even when overall N application rates do not decrease (Bongiovanni & Lowenberg-Deboer 2004).

In absence of more evidence, we suggest using 0.2 t CO_2e ha^{-1} abatement rate.

The applicability of PF depends on the proportion of fields that would positively respond to a variable application rate of N fertilisation. This was estimated to be 20%, 25%, 40%, 30% on grasslands, cereals and oil seeds, root crops and other crops, respectively (Moran *et al.* 2008). Again, due to the lack of any other estimates, we suggest these data be used in the subsequent calculations.

These applicability rates would cover 425,424 ha land area in Scotland in 2022 (based on the FAPRI-Scotland projections), which, multiplied by the abatement rate gives an abatement potential of 85 kt CO_2e in Scotland, assuming 100% uptake of the measure.

Interactions with other GHG measures would exist for PF, with N efficiency measures affected most. IF estimates, referring to 100% overlap of measures, are given in Table 1. Central interaction factor estimates (after accounting for the applicability of the measures – see (MacLeod *et al.* 2010) for more on methodology) are given in brackets. As an example, the abatement potential of "Avoiding N excess" will potentially be reduced by 30% if PF is also feasibly applicable in Scotland.

Table 1 Estimated interaction factors

Measure name	Estimated IF	Measure name	Estimated IF
Using biological fixation to provide N inputs (clover)	0.55 (0.7)	Nitrification inhibitors	0.55 (0.7)
Reduce N fertiliser	0.55 (0.7)	Improved timing of slurry and poultry manure application	0.9 (0.96)
Land drainage	1.05 (1.01)	Adopting systems less reliant on inputs	0.55 (0.7)
Avoiding N excess	0.55 (0.7)	Plant varieties with improved N-use efficiency	1.0 (1.0)
Full allowance of manure N supply	1.0 (1.0)	Separate slurry applications from fertiliser applications by several days	0.9 (0.96)
Species introduction (including legumes)	0.55 (0.7)	Reduced tillage / No-till	1.0 (1.0)
Improved timing of mineral fertiliser N application	0.9 (0.96)	Use composts, straw-based manures in preference to slurry	1.0 (1.0)
Controlled release fertilisers	0.55 (0.7)		

The potential environmental benefits go beyond direct N_2O savings: better utilisation of the applied nitrogen reduces nitrogen leaching and thus diffuse water pollution and indirect N_2O emissions, the reduced machinery runs minimise the area of land prone to compaction (further reducing N_2O emissions) and GHG the emissions from fuel use, and the reduced agrochemical use decreases the pollution load on soil and water bodies. A literature review on environmental effects is provided by Bongiovanni and Lowenberg-Deboer (2004).

4.3. Financial benefits and costs

Financial benefits from PF include reduced fertiliser and agrochemical use, reduced fuel use and higher yield, while on the cost side the items are equipment purchase, maintenance, training and soil/crop monitoring costs.

The annual financial benefit, considering yield and N use, was £22 ha^{-1} on average in 2001 (Godwin *et al.* 2003a). The PF technology used was variable rate N fertilisation based on aerial digital photography (ADP) of the crop canopy structure for wheat and barley in South England, with N fertiliser prices at £300 t^{-1} and crop prices at £65 t^{-1}. Financial benefits in the scientific literature range from -£11 ha^{-1} to £74 ha^{-1} from various PF practices (Boyer *et al.* 2011, Godwin *et al.* 2003a). Since 2001 N fertilisers and crop prices have increased substantially: in 2010 they were £562 t^{-1} and £122-128 t^{-1}, respectively (Scottish Executive 2011). For this reason, using £22 ha^{-1}, we might be underestimating the current benefits.

The financial costs consist of capital investment and annual costs. The former include hardware mounted on the machinery (combine, tractor, sprayer), the associated software, training and possibly some one-off sampling (e.g. soil structure). According to Godwin et al. (2003a), in 2001 a low-cost system (including yield mapping at ±10 m and variable application rates by changing the tractor speed manually according to a target speed suggested by the computer) could be purchased at £4,500, while a fully integrated system (DGPS, removable control system to fit either on the tractor, combine or sprayer) for yield mapping and VRT fertilisation cost £11,500 – £16,200 (see Table 2). Maintenance costs were assumed to be 3.5-8% of the capital costs (depending on the machine type), while training cost was £300. Crop monitoring was done by ADP, at an additional cost of £7 ha^{-1}, but soil sampling costs were not included. These costs (based on 8.5% interest rate and 5 year depreciation) corresponded to £19-25 ha^{-1} and £12 ha^{-1} costs for a farm of 250 ha for the fully integrated and the low-cost system, respectively. The costs are largely reduced for a farm area of 500 ha. The breakeven area for the low-cost system was 80 ha, rising to 300 ha for the most expensive system. Other authors cited in this paper presented costs in a range of £8 ha^{-1} to £15 ha^{-1}.

Table 2 Costs and benefits of variable rate N application in response to crop canopy structure (Godwin et al. 2003a)

	Farm size	Low-cost system	Integrated system
Capital costs (£)		4,500	11,400-16,200
Training (£)		300	300
Maintenance (% of capital cost)		3.5-8	3.5-8
Capital costs + maintenance + training per unit area (£ ha^{-1})	250 ha	5	12-18
	500 ha	2.5	6-9
Crop canopy monitoring (£ ha^{-1})		7	7
Benefits (yield + fertilisers) (£ ha^{-1})		22	22
Benefits – costs (£ ha^{-1})	250 ha	10	-3 - +3
	500 ha	12.5	6-9
Breakeven area (ha)		80	250-300

This analysis covered only variable rate nitrogen spreading, and did not consider variable rate seeding, herbicide or pesticide application. Saving in fuel use was not included either.

Case studies on the benefits and costs of PF technologies can be found on the HGCA website[1], with farmers reporting on capital costs of £4,500 to £37,000, mostly between £12-18,000 against annual benefits of £6-15,000. The size of these farms vary between 300 ha and 1,250 ha.

All in all, financial benefits of PF technologies tend to recover the costs for bigger farms. In the future the increasing trend in crop and input prices and the decreasing technology costs will probably make PF profitable on medium size farms as well.

4.4. Future uptake

To help us estimating the future uptake, two sources of information are available for PF: surveys about adoption in other countries, and the estimated profitability of PF for different farm sizes in the UK in 2001.

According to various surveys, early PF adopters have bigger farms, e.g. in 2001 in the UK 95% of adopters had farms bigger than 200 ha (Pedersen *et al.* 2001), while in 2009 in Germany the median of PF users farm size was 250-380 ha (Reichardt *et al.* 2009).

During the past decade, the number of farmers using PF technologies has been growing steadily: in Germany from 2001 to 2006 the proportion of farmers using PF grew from 7% to 11%, while the rate of uninformed farmers dropped from 46% to 28% (Reichardt *et al.* 2009), among the grain growers of Australia it increased from 5% in 2006 to 20% in 2012 (Robertson *et al.* 2012), and a survey in Ohio showed that by 2010 39% of all farms and 48% of farmers with gross sales over $100,000 have already adopted PF (Diekmann & Batte 2010).

Farmers, who have already adopted the technology or are planning to adopt it have done so mainly because of the expected higher profitability and also the ability to have better knowledge of the fields (Diekmann & Batte 2010, Reichardt *et al.* 2009).

The following barriers were mentioned mostly by farmers in the USA, Europe and Australia (Diekmann & Batte 2010, Reichardt *et al.* 2009, Reichardt & Jurgens 2009): low awareness, time requirements to get used to the technology, lack of technical knowledge, incompatibility of machines of different manufacturers, high cost of the technology and the difficulty in quantifying the benefits of PF.

Economic analysis by Godwin et al. (2003a) showed that in 2001 low-cost PF technology could be profitable from 80 ha farm size, while the breakeven area for integrated systems were 250 ha. As cereal and N fertiliser prices have doubled since then, while the cost of the technology stayed stable, the breakeven area has decreased and the profitability of PF on medium sized farms has improved. This trend is likely to continue. The assumption that uptake is going to increase in the future is also supported by the findings that PF adopters are more likely to be younger (Diekmann & Batte 2010) and to have college or university degrees (Diekmann & Batte 2010, Reichardt *et al.* 2009) – the general trend is increasing level of education and younger generations are going to be more familiar with information technology.

Considering the farmed area of non-LFA farms in Scotland, 23% belongs to farms bigger than 200 ha, 34% belongs to farms between 100 and 200 ha, and a further 21% belongs to farms of 50-100 ha in size (Scottish Government 2011). Assuming that in 2022 the profitability threshold of PF will be 100 ha, more than 50% of the farms are going to be adopters purely on a financial basis. Allowing for barriers still to exist, 20% uptake in 2022 seems to be a cautious estimate.

This brings the total abatement potential to 17 kt CO_2e.

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[1] http://www.hgca.com/content.output/5194/5194/Crop%20Research/Crop%20Research/Precision%20farming.mspx

As the applicability rates and the uptake might be underestimated, this abatement potential is a conservative estimate. Using more optimistic assumptions (50% applicability in all land categories, and 50% uptake), the abatement potential would be:

$0.2\ \text{t}\ CO_2\text{e}\ \text{ha}^{-1} * 962{,}855\ \text{ha} * 0.5 * 1000 = 96\ \text{kt}\ CO_2\text{e}$.

Further information

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