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Abstract and Summary

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An up-to-date cost / benefit analysis of precision farming techniques to guide growers of cereals and oilseeds

by

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Abstract

Precision farming techniques have a potentially important role in addressing the conflicting demands and constraints on combinable crop production. Economic benefits may result from higher yields, saved inputs or faster work rates, and depend on farm size, cropping and the amount of soil, crop or yield variation as well as crop values and input prices. Practical and environmental benefits may also be obtained as a result of decreased operator dependence and reduced input wastage respectively. The price, replacement value and lifespan of the equipment needed have a significant impact on annual cost. GPS guidance systems have been a significant development, offering good prospects of achieving a benefit over cost of at least £2/ha on a 500ha farm. Pass-to-pass accuracies of +/-10cm or less, and adding auto-section sprayer boom control, enable savings from reduced input overlaps to be maximised. Determining the extent of variability in soils, growth or yield is essential to decide the best strategy for managing inputs. Mapping soil texture using electrical conductivity, remote sensing of crop canopies and yield mapping can provide useful information and could cost as little as £1-2/ha each for a 500ha farm.

Variable rate application of P & K fertilisers can be based on nutrient offtake and targeted sampling derived from yield maps, or soil nutrient maps obtained by grid sampling, at a total cost of £6-7/ha. This could protect yield worth an average of £5/ha and save fertiliser worth £3/ha or more on a 500ha farm with 250ha treated variably. Variable rate N fertiliser is only justified in fields with large variation in crop canopy. For a 500ha farm with 250ha of wheat and oilseed rape treated variably, estimated benefits are £9.50/ha at a total cost of £5/ha for a satellite-based service or up to £8/ha for a vehicle-mounted system. The case for agrochemicals is weaker. An economic benefit from variable rate PGRs is unlikely unless their costs increase or their use is restricted. There are significant practical barriers to the patch spraying of herbicides, but variable treatment of 250ha of cereals on a 500ha farm could give savings of up to £9/ha at a cost of about £7/ha.

As the equipment and services involved could be used in multiple techniques, the benefit over cost of the whole system should be considered. Potential net benefits of around £6, £10 and £19/ha were calculated overall for farms of 300, 500 and 750ha respectively. Guidance was one of the main contributors to the benefits, and for many growers this would represent the lowest risk entry into precision farming.

Summary

Introduction

Precision farming technologies and techniques have a potentially important role to play in helping growers to address the conflicting demands and constraints that they face within current combinable crop production systems. However, the economic benefits that might be obtained by individual growers from the many options open to them depend on their farm size, cropping and the amount of variation that is present on their farms, as well as crop values and input prices. The analysis in this report is based on a 500ha farm growing:

- 125ha of feed wheat (yielding 8.0 t/ha at £100/t)
- 125ha of breadmaking wheat (yielding 8.0 t/ha at £120/t)
- 125ha of oilseed rape (yielding 3.5 t/ha at £240/t)
- 62.5ha of spring barley (yielding 6.5 t/ha at £130/t)
- 62.5ha of field beans (yielding 3.25 t/ha at £120/t).

The costs of fertilisers, pesticides or other inputs are based on expected prices in 2009.

The numbers of fields on the farm (as a percentage of the total) that are assumed to have significant variation are:

- 50% with variation in soil texture (mainly medium, some light and some heavy soil)
- 50% with variation in harvest yield (within-field variation of 10% or more above or below the field average)
- 67% with variation in crop structure (within-field variation in canopy GAI at the start of grain fill of 20% or more above or below the average for the field)
- 80% of fields with variation in their weed populations (fields are considered to have patchy weeds if a given species occupies less than 67% of the field).

The major financial investment from adopting precision farming methods is usually the purchase of the equipment, although the annual cost of bought-in mapping services can be higher. The extent to which that equipment comes as standard on the specification of machine normally being purchased, the period over which it is depreciated and its value at replacement can all have a significant influence on the annual cost per hectare of the technique that is being considered. For this analysis, straight-line depreciation of 17% per year has been assumed, with a replacement value after 5 years of 15%, and capital

interest of 6% charged on the mean value. However, to achieve success also requires a reasonable investment in time, for training, analysing data and setting-up equipment, as well as a willingness to have faith in the technology.

Economic benefits may be derived from a combination of increased yields, saved inputs, faster work rates and possibly improved timeliness. The array of other potential benefits though may itself provide a compelling argument for the use of some techniques. Most growers gain satisfaction from a ‘job well done’, and precision farming enables the accuracy of operations and applications to be improved (or maintained for longer or at higher work rates) whilst reducing operator fatigue. Matching input use to local crop need, or reducing treatment overlaps, are not only sources of financial saving but also help to minimise exposure and wastage in the environment, the benefits of which may be hard to quantify but nevertheless invaluable in addressing government policy objectives.

Machine Control

The introduction and commercialisation of guidance systems (using Differential GPS) for agricultural vehicles has been one of the most significant developments in precision farming within the current decade. In addition to its potential economic advantages, guidance offers a range of other practical and environmental benefits. Equipping two vehicles with an entry-level manual-steer system achieving a pass-to-pass accuracy of +/-40cm is likely to cost around £1.25/ha per year on a 500ha farm, but deliver potential savings of £2.50/ha from reduced overlaps (mainly during cultivations). This option is likely to be the most cost-effective for farms of about 300ha or less.

At least half of the potential savings from guidance systems come from saved spray and fertiliser inputs. To obtain these, tramline (and therefore drill) overlaps must be reduced to less than those achieved with conventional marker systems. This is only likely with medium-high accuracy guidance systems achieving pass-to-pass accuracies of +/-10cm or less, which would require a paid-for DGPS correction signal and either assisted or auto steering. The typical cost of equipping two vehicles with such a system on a 500ha farm is likely to be about £12/ha per year, but could deliver savings of around £14/ha.

An RTK-based system achieving a pass-to-pass accuracy of +/-2cm would cost considerably more, at around £20/ha per year for a 500ha farm (including auto-steer on three vehicles). Potential savings would also increase to around £22/ha. This option is unlikely to be cost-effective on less than 500ha of combinable crops, and is probably best suited to very large farms or those growing higher value / cost crops. The high accuracy of location and steering that is possible with an RTK system also facilitates the adoption of controlled traffic farming (CTF). Potential benefits of CTF include better soil structure, improved water infiltration rates and lower draught requirements, leading to higher yields with reduced cultivation costs. There may be some additional expense in ensuring that matched equipment is purchased, and in maintaining the permanent tramlines. Data from two sites suggests that yield increases of 2-5% over trafficked non-inversion cultivation systems are feasible on most soil types in the short term. This could increase winter wheat returns by £16-40/ha. RTK might also have a value where the intention is to use strip tillage, to enable accurate matching of cultivated strips and drill rows.

Adding auto-section boom control to a sprayer could further reduce overlaps (on headlands and at field edges), for an annual cost of less than £1/ha on 500ha. This would typically be recouped by a reduction in the total quantity of pesticides used of only 0.5-1.0%.

Assessment of Variation

Determining the extent (and causes) of variability in soil parameters, crop growth or yield is essential in order to decide the best strategy for managing inputs or treatments. The factors that vary within a field are no different to those that vary between fields, and a rough assessment of variation is possible without investment in precision farming through routine inspection of crops and problem areas, existing farm maps and aerial photos, or free satellite images (from previous years) available on the internet. These can be used to indicate the need for more detailed investigation.

Differences in crop requirement or performance across a field will often reflect changes in soil properties. Mapping variation in the apparent electrical conductivity (ECa) of the soil can be used to define more accurately the boundaries between different soil textures, provided that the soils are mapped at field capacity, and soil pits are dug or cores taken to verify the differences in soil properties. ECa mapping is offered as a commercial service which, if spread over 10-15 years, would equate to cost of about £1-1.50/ha.

Mapping crop yield produces rapid and data-intensive information about variation that could be economically important. Data must though be analysed correctly, and trends that are stable over a number of years identified, in order for the information to be most useful. The likely cost of yield mapping on a 500ha farm would be around £3/ha per year, but less than £2/ha where the same equipment is shared with other tasks. Variability related to site or soil features will often be evident within a field as differences in size or colour of a growing crop. Remote sensing technologies that measure spectral reflectance form the basis of several commercially-available options for quantifying such variation. Systems differ in terms of area scanned, the wavelengths used, spatial resolution and the way that the impact of cloud or varying light levels is accounted for. The main decision for growers is the choice between an annual bought-in (satellite-based) service whereby all of the data collection, analysis and interpretation is done by the service provider and made available to the grower within a few days (near real time); or a vehicle-mounted sensor system owned (or rented) and operated by the grower, with data available instantly for on-the-go adjustment of crop inputs in real time.

The major cost difference is the initial investment and the greater impact of farm size or usage area for owned equipment compared to a bought-in service. The cost of obtaining crop canopy maps using a satellite-based service would typically be about £2/ha for a 500ha farm. This does not include the cost of the application maps for N or other inputs, which would be necessary in order to vary inputs. Using the Yara N-Sensor as an example, obtaining similar information from a purchased vehicle-mounted system is likely to cost around £6.50/ha per year on 500ha (less as farm size increases), but any additional expense associated with translating the canopy information into a variable rate of N or other input should be less.

Managing Limitations to Crop Performance

Having established that significant variation exists, an appropriate response must then be determined. It might be possible to improve average performance within a field, by not cropping problem areas or through targeted remedial treatments. Alternatively the variation could be managed through better targeting of inputs, which could be as simple as manually-triggered adjustments in one or two areas of a field. In addition to variability within a field in one season, there will be season-to-season differences. Strategies that are based only on the former and that ignore seasonal interactions are risky and could exacerbate the range in performance achieved. It must also be recognised that in most cases precision farming helps a grower to decide where to do something, not what to do. The actual techniques used are therefore only as reliable as the agronomic rules and interpretation that go with them.

Mapping the crop canopy or yield enables losses caused by waterlogging, rabbit damage or uneven N fertiliser application to be quantified and targeted. It can also be determined from yield maps whether or not remedial actions are likely to be worthwhile, and their subsequent impact can then be monitored. Compaction can be linked to variation in growth or yield, or mapped directly using a commercial service that involves measurement of penetrometer resistance at different depths within a field on a grid basis. The soil profile must be inspected and soil moisture taken into account to ensure that data is properly interpreted. The cost for this service is about £12/ha, but should only be required every 3 or 4 years. Reducing by half the amount of subsoiling required on 100ha each year, or improving yield by 5% on 50ha each year, would typically be sufficient to cover the annual costs incurred.

Crop Establishment

Reducing the potential variation in crop structure should ideally start at establishment, by compensating for the impact of variable seedbed quality caused by differences in topsoil texture. Varying seed rates based on maps derived from ECa mapping provides a means of achieving this. Where fields have distinct areas with different soil types, seed rates can be adjusted manually. The cost of adding a variable seed rate controller to a seed drill (already fitted with electrically-operated seed rate adjustment), and producing seed rate maps from ECa maps, is likely to be around £1.50/ha per year. Assuming that only 50% of fields have sufficiently large soil variation to justify variable seed rates, average savings in seed costs alone on a 500ha farm might only be around £1/ha. However if a 1% yield loss could be prevented on heavier patches that might otherwise end up with sub-optimal plant populations, benefits should be sufficient to recoup the costs of the variable seed rate capability and a share of the ECa mapping cost. Preventing a 1% yield loss also on lighter soil patches that might otherwise lodge due to excessive plant populations could give benefits sufficient to cover the full cost of ECa mapping.

Nutrient Management

There are two main approaches to determining variation in requirement for phosphate (P), potash (K) and magnesium (Mg) fertilisers within a field. Yield maps can be used to identify areas of consistently low or high yield where differences in offtake may have resulted in above or below target soil nutrient indices respectively. An intensive targeted sampling approach within these areas can then be used confirm this, and application maps produced based on replacement of crop offtake and also the need to raise or lower indices, taking into account any soil texture variation. Alternatively, the whole field can be sampled on a grid basis by a commercial service provider, allowing application maps to be produced based on soil indices. In both cases, sampling itself would only take place about once every four years, although applications would be varied on an annual basis.

Due to the relatively high cost of soil sampling and analysis, it is not cost-effective to obtain more than one (bulk) sample per hectare, which means that when grid sampling interpolation is necessary for areas of the field in between. This can be a source of error, especially where there are unusual patterns in the distribution of nutrient indices within the field. Where yield maps show consistent and discrete high and low yielding areas within a field, and the previous field history is well know, targeted sampling might be a more cost-effective approach. Where such information is not available to target sampling, an unbiased grid survey may be a more useful starting point.

A commercially-provided grid sampling service is likely to cost about £5.50/ha per year over the four year life of the information. A strategy based on targeted sampling is likely to cost nearer £4.00/ha on a 500ha farm, or £2.50/ha if only half the fields have sufficient yield variation to justify variable treatment. A variable rate spreader controller is likely to cost no more than £0.75/ha per year, assuming that the expense can be shared with variable N application. Savings in P & K fertiliser may be small, unless the farm has a history of over-applying nutrients in excess of offtake. There will be some savings in low yielding areas, and by restoring indices to target levels in higher offtake areas this should ensure no loss of yield potential. If 50% of fields on 500ha are treated variably, averaged over the whole farm saved yield could be worth £5/ha and P & K fertiliser savings could amount to £3/ha or more (where average soil indices are currently above target). This would give a potential net benefit equivalent to about £2/ha over the whole farm.

For spatially-variable application of nitrogen (N) fertiliser to be justified, the optimum N dose for a crop must vary significantly within a field. Evidence suggests that this does occur, but the impact of seasonal variation in N response will often be greater and annual application strategies must account for this. Canopy size and colour, mapped by remote sensing of reflectance, provide the best means of determining the interaction between spatial and seasonal impacts on N supply and crop requirement, and this forms the basis of most commercially-available systems for determining variable N applications. The most appropriate response for crop areas with above or below average canopy size may vary according to growth stage or other factors, but typically the objective is to increase growth in areas that are below target early in the season and hold-back growth in areas that are above target. Later the strategy may be reversed to avoid over-fertilising areas of low yield potential or under-fertilising areas of higher potential. A re-analysis of previous HGCA-funded research suggests that for winter wheat only where crop canopies in May vary by more than about 20% above or below target, which may equate to earlier plant or shoot populations varying by more than about 40% above or below target, is variable N application likely to be justified. It can be estimated that no more than half of all wheat fields (perhaps a larger proportion of oilseed rape fields) are likely to benefit.

In addition to the expense of satellite-derived canopy maps indicated earlier, the annual cost of generating N fertiliser application maps can be estimated at £1.50/ha per map (£4.50/ha per year for wheat or £3.00/ha for other crops). With the canopy mapping and a share of the cost of the variable rate spreader controller, the total cost for this approach is likely be around £6.50/ha for a 500ha farm. Assuming 250ha of wheat and oilseed rape are treated variably (and require treatment maps), the costs (averaged over the whole farm) would be £4.75/ha. The only additional costs for a vehicle-mounted system like the N-Sensor would be in setting up the system to translate the crop canopy information into a variable N dose, which can be estimated at about £0.50/ha per application (£1.50/ha per year for wheat or £1.00/ha for other crops). With a share of the spreader controller costs, the total for this approach is likely to be around £8.25/ha for a 500ha farm, or if used on 250ha of wheat and oilseed rape then £7.50/ha (averaged over the whole farm).

Potential benefits can be estimated at an average 2% yield increase, from re-distribution within a field of the same total quantity of N fertiliser, or alternatively a 10% reduction in the total quantity of N applied to a field to maintain the same average yield. The potential improvement in margin over N cost would then be around £15-20/ha. For a 500ha farm with 250ha of crops that are treated variably, this would equate to an average benefit over the whole farm of £9.50/ha, giving a net benefit of £4.75/ha with the satellite-based approach or £2.00/ha with the vehicle-mounted system. Increasing the area farmed to 750ha would reduce the costs of the vehicle-mounted system in particular and increase the net benefits for the two approaches to around £5.25/ha and £4.25/ha respectively.

Crop Protection

Crop structure in spring can be a useful indicator of lodging risk. Maps obtained using remote sensing could provide an indication of how risk varies within a field, if properly calibrated and correctly interpreted. These could be used to produce variable application maps for Plant Growth Regulators. As the potential penalties caused by lodging vastly outweigh the likely savings in PGR costs, a treatment strategy based on varying the dose applied would be more appropriate than a spray / no-spray strategy, except perhaps for late-season applications. In addition to a share of the costs of the canopy sensing and patch spraying capability, described later, the only expense would be in producing the variable rate PGR maps. The total cost on 500ha can be estimated at £3.75/ha per year (averaged over the whole farm), assuming 167ha of wheat treated variably. Savings in PGR cost alone are unlikely to reach this even on a much larger area. Assuming that 5% yield loss could be prevented in areas where the canopy size is excessive, the benefits would just about cover the cost of variable rate treatment. In practice, variable application rather than a robust uniform treatment is only likely to be adopted if PGR use becomes restricted or if the costs of the PGRs themselves increase significantly

The evidence for variable rate application of fungicides in response to predicted differences in disease development or fungicide requirement is conflicting and relatively weak. Based on our current capabilities and understanding, the conclusion must be that there is unlikely to be an economic benefit from varying fungicide application to combinable crops in the foreseeable future.

The principles for variable rate application of herbicides are well established, although some debate remains on the stability of weed patches. This affects the most appropriate mapping frequency and potentially the most suitable treatment strategy (including the size of the safety margin around the patches), all of which have an impact on the cost. Investment in the patch spraying capability and associated expenses can be estimated at £4.00/ha per year for a 500ha farm. A strategy based on mapping weeds every two years at a cost of £6/ha would make the total cost £7.00/ha per year. Assuming 80% of the farm's cereal area (250ha) has patchy black-grass, cleavers and wild oats, savings on specific post-emergence herbicides can be estimated at about £9.00/ha, with a potential benefit over cost of £2.00/ha. If only 50% of the cereal area had patchy weeds, variable rate herbicides would not be cost-effective unless the patch spraying equipment expense could be shared with variable rate PGR application. Increasing reliance on pre-emergence herbicides, a tendency for most growers to adopt a zero-tolerance strategy for managing the weed species for which patch spraying has been evaluated, and difficulties involved in weed mapping are however significant barriers to uptake of this technique.

Traceability and Record Keeping

Precision farming techniques offer the potential to contribute to the generation and maintenance of records of most farming operations. There is a legal requirement to keep records of the application of crop protection chemicals (pesticides) and some fertilisers. Such records need to contain information relating, for example, to the date and time of an application, the crop to which the application has been made, the materials applied (both dose and relevant ingredients), the weather conditions at the time of the application and the justification for the treatment. Application systems with a precision farming capability are able to start the creation of such records automatically including in situations where spatially variable applications have been made. To date however, no commercially viable method of detecting what is loaded into a sprayer tank or fertiliser spreader hopper has been established although a number of research concepts have been identified. Data relating to the materials that have been applied must therefore be entered manually with existing systems.

The cost/benefit of using automated record generation units depends on allocating a value to having accurate records. Some authors have suggested that there would be a time saving associated with part automated record generation while others consider the sole benefit to be in the quality and timeliness of the records produced. In this study, it was concluded that there could be some labour time savings associated with the generation of records having a higher level of accuracy when using precision farming techniques compared with wholly manual methods. No added value has been allocated to records that would be more accurate and reliable. For a typical 500ha arable farm, the labour saving from generation of pesticide application records with precision farming systems but manual entry of products applied was estimated to average £0.27/ha with shared equipment costs of £0.21/ha. This approach therefore gives marginally positive cost/benefits without giving a higher value to more accurate and reliable records. Increasing the farm area increases the benefit. For fertiliser application records, the farm area needs to be at more than 700ha to give a positive cost/benefit ratio.

In addition to records of crop inputs, precision farming approaches will also enable records of other field operations, such as cultivations, to be obtained with greater accuracy and less time than with comparable manual systems. Yield mapping with a correctly calibrated and operated system can generate records relevant to monitoring the output from a defined field area as well as the marketing of farm outputs.

Whole Farm Systems

Many precision farming techniques involve the use of equipment or services that are common to two or more tasks. In some cases the economic benefits from an individual task may be small, and it may not be cost-effective in its own right. However by covering part of the cost of components used in other more cost-effective tasks, the profitability of the overall system may still be improved. An objective of this project was to produce an interactive cost/benefit calculator tool that could be used by a grower to obtain an indication of the individual techniques and overall system that might produce a benefit over cost on their farm, taking into account their cropping, input/output costs and estimated variation. Likely costs and potential benefits were calculated for three example systems for farms of 300, 500 and 750ha. All were based on the same cropping split (50% winter wheat, 25% oilseed rape, 12.5% spring barley and 12.5% field beans).

The 300ha farm system comprised a lightbar-based low accuracy level guidance system, the use of satellite-derived crop canopy maps to vary N application rates, and variable application of P & K based on a grid sampling service. Overall system benefits were calculated to be £20.00/ha, for a cost of £14.25/ha, giving a net benefit of £5.75/ha.

The 500ha farm system comprised a medium-high accuracy guidance system based on a paid-for DGPS signal with part auto / part assisted steering, auto-section sprayer boom control, yield mapping to quantify yield variation, improve farm records and to target low yielding areas (caused by compaction), the use of satellite-derived canopy maps to vary N application rates and variable application of P & K based on a grid sampling service. Overall system benefits were calculated to be £36.25/ha, for a cost of £26.50/ha, giving a net benefit of £9.75/ha.

The 750ha farm system comprised a high accuracy guidance system based on an RTK signal with auto steering on all main vehicles, auto-section sprayer boom control, yield mapping to quantify yield variation, improve farm records and to target low yielding areas (caused by compaction), ECa mapping of soil texture to guide the use of variable seed rates, the use of an owned vehicle-mounted sensor system to vary N and PGR applications, variable application of P & K based on a grid sampling approach, weed mapping / patch spraying of herbicides and improved recording of spray and fertiliser applications. Overall system benefits were calculated to be £55.00/ha, for a cost of £36.00/ha, giving a net benefit of £19.00/ha.

Increasing farm size was associated with an increase in the number of techniques that could potentially be cost-effective and a larger overall benefit over cost for the system. The level of sophistication justified, and the scope to use owned equipment rather than a bought-in service, also tended to increase with farm size. However, timeliness is crucial for many operations and any delays introduced due to precision farming being adopted could easily result in their advantages being negated in the short term. In all three of the example systems above, variable N application and guidance together contribute about 80% of the net benefits. However, as the contribution from variable N application depends heavily on the amount of canopy variation present, for many growers guidance will give the highest probability of an economic benefit over cost and is likely therefore to represent their lowest risk entry point into precision farming.