April 2012

Cost £8.75

Project Report No. 485

Cost-effective sampling strategies for soil management

by

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This is the final report of a 24 month project (RD-2005-3189) which started in April 2009. The work was funded by a contract for £113,744 from HGCA.

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1. ABSTRACT

Efficient fertiliser management requires information about the nutrient status of each management area or field. This information can be gathered by observing soil nutrients at a number of sites in the field. The quality of this information is dependent on the sampling strategy that is employed. The sampling strategies suggested in fertiliser recommendations such as RB209 are generally based on anecdotal evidence regarding the number of soil cores required or are designed to ensure that the errors in estimating soil nutrient concentrations are less than an arbitrarily defined threshold. Such strategies do not directly link the sampling effort to the consequences of erroneous soil nutrient information, which may include reduced profitability or the long term development of nutrient excess or deficiency. We develop a quantitative framework to study the effectiveness of different sampling designs so that rational sampling recommendations for phosphorus (P), potassium (K) and nitrogen (N) can be developed.

For all nutrients, current recommendations suggest that measurements should be regularly spaced on a 'W' design which covers the field. Four alternatives to the 'W' are tested: an optimized sample configuration, stratified random sampling, rank set sampling and a clustered or bad practice design. We quantify the errors associated with each design, determine the management decisions that will be made by the farmer based on this erroneous information and then model the effects of these decisions. Thus we are able to relate the resources devoted to sampling to the expected profitability or long-term nutrient status of the field.

Our study shows, that for a particular sampling effort, sample designs can be optimized to give smaller errors than the 'W' design. However we also find that the errors from estimating soil-nutrient status with a 'W' are not large enough to substantially affect the quality of soil nutrient management. This is because once a certain accuracy in estimating soil-nutrient concentrations has been achieved, the quality of the management recommendations are limited by other sources of uncertainty in predicting the amount of nutrients the crops will access from the soil. Therefore the benefits of using optimized designs do not outweigh the extra complexity which they entail. If in the future fertiliser recommendations are more sensitive to soil information, say for example if nitrous oxide emissions had to be carefully controlled, then the use of optimized sample designs should be re-explored.

We find that in the scenarios explored in this project, decisions regarding K require less accurate information than P. A bulked sample every four years of 10 soil cores is sufficient to maintain both soil P and K stocks within a target range. This is less than half of the number of cores which is currently recommended. For N, rational sampling effort varies according to the expected SNS in the field, and the field size. Bulked samples of 10-15 soil cores are adequate for most fields. Including more than 10 cores in the bulked sample is warranted when fields are larger than 20 ha or if SNS is expected to be high (>160 kg/ha). The largest financial benefit from sampling occurs when soil nitrogen supply is around 175 kg/ha since at these concentrations the yield is most sensitive to sampling errors and erroneous decisions. There is a smaller benefit when the expected SMN is much larger or much smaller since in these circumstances it is clear that either a small or large amount of N fertiliser should be added. We determine the circumstances in which SMN measurement and the use of barometer fields are cost effective in comparison to prior knowledge of SMN. We do not consider alternative methods of estimating soil nitrogen supply such as the Field Assessment Method.

The framework developed in this project is not only suitable to assess the cost-effectiveness of different sampling designs under current fertiliser recommendations but also to develop and assess the cost-effectiveness of modifications to these recommendations.

2. SUMMARY

2.1. Introduction

Efficient fertiliser management requires information about the soil-nutrient status within each management area or field prior to fertiliser additions. The soil-nutrient status can be estimated by bulking a number of soil cores from different sites within a field. The accuracy of such an estimate increases with the number of cores extracted but so do the time taken and the costs of sampling. Current recommendations for soil sampling are based primarily on anecdotal evidence of what sampling is sufficient. They do not relate the sampling effort to the consequences of erroneous soil nutrient information. These consequences might include reduced profitability or the long term development of nutrient excess or deficiency.

RB209 suggests that for phosphorus (P) and potassium (K) a bulked sample of 25 cores will be adequate for a uniform area and that a 'W' design will ensure an even distribution over the whole field. For soil mineral nitrogen (SMN), RB209 suggests a minimum of 10 individual sub-samples should be taken from the sampled area and more if practically feasible. The HGCA *Nitrogen for winter wheat – management guidelines* suggest at least 15 cores in each field where SMN analysis is undertaken and 20 in more variable fields. Both RB209 and the HGCA guidelines emphasize that costs of SMN analysis will prohibit sampling in every field and that sampling is most worthwhile where large and uncertain soil nitrogen residues are expected.

We showed in a previous HGCA project that it is possible to optimize the sample designs to perform better than the 'W' in terms of sampling errors per core taken. However such schemes might not be as simple to implement in the field. These factors suggest there is a need to assess the sampling requirements for soil nutrient management so that the best sampling design and the rational sampling effort (i.e. number of cores) can be determined.

2.2. A framework for assessing sampling requirements for nutrient management

Field experiments to compare the relative merits of different sample designs would require an impractical number of soil cores to be extracted and analysed. Therefore a computer-based framework to compare sample designs is developed in this study. Typical patterns of the variation of soil nutrients are simulated based on existing datasets. These simulations are sampled and the mean soil nutrient requirement is estimated according to the various proposed sample designs. The implications of basing fertiliser management on these estimated values are explored and compared using mathematical models of soil nutrient management decisions, soil nutrient dynamics and crop responses to nutrients.

2.3. Comparison of different sample designs for estimating field-mean soil nutrient status.

The simulation tests confirmed that optimized sample designs do estimate the field-mean P, K and SMN concentration more efficiently than the ‘W’ design. However the improvement in efficiency is only substantial when more than 15 cores are bulked. It was found that the accuracy of the ‘W’ design is sufficient for current fertiliser recommendations. However if future fertiliser recommendations require more precise fertiliser management, such as if nutrient leaching or nitrous oxide emissions have to be more carefully controlled, then the use of optimized sample designs should be reconsidered.

2.4. Sampling recommendations for soil nutrient status

The sampling tests suggest that 10 bulked cores selected from a ‘W’ design every four years are sufficient to maintain soil P and K concentrations within the ideal RB209 index. The number of cores required is largely independent of field size and is less than half of the number of cores currently recommended.

For SMN, 10-15 cores are adequate for most fields. More than 10 cores are warranted for large fields (>20 ha) where SNS is expected to be high (>160 kg/ha). Sampling requirements increase with field size and 23 cores would be most cost-effective for a highly variable 60 ha field. We do that envisage that such fields are common in the UK. The study suggests that for some small fields where SNS is likely to be small or moderate (below 120 kg/ha) a bulked sample consisting of fewer than 10 cores is most cost-effective. However in such circumstances it is likely that the field assessment method would be used in preference to direct measurements. Therefore where SMN is measured we recommend that a bulked sample should be formed from 10-15 cores which are located on a ‘W’. The use of barometer fields is seen to be efficient for small target areas with low variability such as clusters of small fields where N requirements are not expected to differ. More widespread sampling should be considered in other circumstances.

The scenarios and models for P and K in this project were relatively robust. However the scenarios for SMN required assumptions about the price of wheat and fertiliser and the quality of the practitioner’s prior knowledge of nutrient stocks. If these assumed values change or if more information of the complex dynamics of SMN become available then the sampling recommendations should be recalculated. Alternative methods of estimating soil nitrogen supply such as the Field Assessment Method are not considered here but are addressed in *HGCA Project 3425 Establishing best practice for SNS estimation*.

2.5. Delineation of regions of soil-nutrient excess or deficiency within fields

Previous studies have demonstrated the potential for regions of soil-nutrient excess or deficiency to appear in fields under uniform management. These might arise because of variation in yield and hence nutrient off take. There is a need to identify these regions so that limitations on yield and excessive emissions to the environment can be avoided. In surveys of soil pollution, sequential sweep-out methods are used to efficiently identify pollution hotspots. These methods adopt an efficient bulking strategy to reduce the laboratory costs of conducting the survey. However we found them to be ineffective for soil-nutrient surveys because the variation of the nutrients is much less extreme than the variation of contaminants observed close to sources of pollution.

2.6. Future application of the computer-based framework

The framework used to assess sample designs in this framework could be extended to compare and evaluate future fertiliser management recommendations. This would require extensive analyses of existing soil-nutrient data and perhaps further field experiments to determine the relationships between soil nutrient status, fertiliser additions and crop yields under various soil and climate conditions. Such issues have been addressed in HGCA Project 3425 *Establishing best practice for SNS estimation*. Critically the uncertainty associated with these relationships should be quantified. It is also important to understand how the relationships can be scaled from experimental plots up to the field or farm scale. The framework developed in this project would then be suitable to process this information and rationally determine the most cost-effective fertiliser management procedures. It would also be possible to devise recommendations which efficiently combine SMN observations with the Field Assessment Method or to develop decision support systems for individual farms which, over a number of seasons, adapt recommendations to the specific needs of the farm.