USING PRICISE GPS/GIS BASED BARLEY YIELD MAPS TO PREDICT SITE-SPECIFIC PHOSPHORUS REQUIREMENTS

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ABSTRACT

Three fundamental stages and technologies as main parts of a precision farming project should be considered precisely. These are access to actual multi-dimensional variability detail or variable description on farms, creating a suitable variable-rate technology, and finally providing a decision support system. Some results of a long term practical research conducted by the author in Upon-Tyne Newcastle University of UK for reliable yield monitoring and mapping were utilised to prepare this paper.

The objective of this study is preparing a plan to predict variable rated P requirements spatially in frame-work of this new idea. Using the conventional method of uniform rated fertiliser planning within a field or a hectare unit, we can predict the variable required fertiliser (kg/ha) for each crop spatially based on the previous year's yield mean (t/ha) and soil analysis within each field. In Britain, the soil analysis results of macronutrient such as P, K are classified into 9 indices (MAFF, 1994). Hence, average soil index and previous year's yield map of each field with or without straw removal were used to predict VRP fertiliser recommendations for the wheat or barley.

As the first trails in England, some tests, due to electronically yield data logging aided by GPS and mapping in GIS, were done on Nafferton farm of Newcastle University. The author tried to use the information and process these data for the above objective. For instance, further processing of the regular normalised yield data was prepared to predict variable rates, phosphorus off-take maps of East-Hemel field in 1995 and 1996. The study showed although the resultant maps, analytical and statistical considerations could be used to determine site-specific P requirements within each small grid of a field, however, for more precise and confidential conditions of accumulation of yield data collection in several years integrated other points such as soil index and landscape, crop and climate factors also may are required subsequently.

Keywords: Yield map, Site-specific P requirement, GPS, GIS, Soil index

INTRODUCTION AND OVERVIEW

In Precision Farming, as a new technological management of agricultural affairs, reliable historical records of both yield and soil maps based on a synchronised griding network system with identical square grid spacing can help to predict the actual spatially variable fertiliser requirements for higher qualified production in each management zone of fields. To day, we know three fundamental technologies as main parts of a precision farming project should be considered precisely (Yule, et al.1995). These vital elements of this new technological management issue for optimising and balancing agricultural inputs and crop yields are: **a-**data logging, mapping of <u>explaining effective variables</u> and their analysis for any related specification of environment, soil and crops , **b-**introducing a suitable <u>variable-rate technology for each variable input</u>, and **c-**creating a comprehensive <u>decision support system</u> for next reliable implementation.

Therefore two data sets of yield and soil samples for the same sampling area can be compared and evaluated to predict the required nutrient in each cell and management zone based on determination of nutrient removal by the crop and remaining soil nutrient content (Vanschen & De Baerdemaeker, 1991). The informative yield maps of 3-5 years integrated to other important factors such as soil properties, landscape, climate and crop conditions may help to predict each spatial variable rated application as Kitchen et. al. stated (1995).

In this paper, as the main objective of the study, following same studies conducted by some other researchers, the author also tried to access reliable results to predict Spatial Variable P Requirements within each small grid of a field. For this, some results of a comprehensive research via laboratory, field and workshop practices conducted for reliable yield monitoring and mapping on the combine harvesters aided by GPS/GIS were utilised to prepare this paper (Sanaei and Yule 1996a, b, Sanaei, A. 1999).

MATERIALS AND METHODS

The parts of information and collected data related to yield variability *within* and *between* fields and years by the author were used to create more practical yield maps. Using the most accurate fault interpolation technique helped to create normalised yield maps as previous contributed to relieve one of the requirements to mask out areas that were sparsely sampled so that they will not overly influence the composite estimate (Sadler et al, 1995). Thus, it allows data from multiple years to be aggregated into a single objective yield map that is associated with improving utility of different annual yield maps.

More often these maps are identified as practical management tools in both agriculture (as were utilised here to predict variable rates P fertiliser for following crop) and public sectors to improve field treatments or practices towards more economical use of resources for farmers and preservation of the environment. The important stage of map interpretation requires reliable information of yield variability sources within field and between years.

Indeed, without the sufficient genuine reasons for each local yield variation, these maps can't be further processed to improve farming system. Hence, following conducted complete series of field and workshop tests and electronically data logging of small grain cereal yield (here for barley using RDS Tech. Ceres2 Yield Meter) for mapping in various GIS packages. for accessing highest precision and accuracy of logged data, other some more fruitful comparative data processing also were done as follows. Implementing of these tests was done in different fields on Nafferton research farm of Newcastle University in England.

For instance this paper explains a further processing of the regular normalised yield data which was prepared statistically to predict variable rates of phosphorus off-take maps of East Hemel field in 1995 and 1996. In this way, as well as GIS (Arc/Info, Surfer and Unimap as interactive packages) the spreadsheet of Excel was also used to calculate optimum fertiliser (P_2O_5) t^{-1} requirements for each grid square separately.

In usual conditions, the phosphorus removed from the soil in the cereals is approximately 7.5 kg P_2O_5 /t for wheat and barley with straw ploughed in soil (MAFF, 1994 & 1997) which was used in this project to estimate P off-takes in each small grid square and predicting phosphorous variable rate requirements.

RESULTS

The calculated average P off-takes for average yield in 1995 and 1996 were 55.6 and 53.2 kg/ha respectively. The subtracted P off-takes related to years of 1995 1996 showed a difference of 2.46 kg/ha which is the same as the difference between total average P off-takes.

The average of P off-takes: kg/ha in the same classes between 1995 and 1996 (Table 1- last column & row) show relatively similar values. This means that a similar average of P maintenance will be required in same class (as management zone) between 1995 and 1996.

Different proportions of total area are covered by each P off-take classes while Z4 (1995) and Z3 (1996) indicate a larger area (31.02%). P off-take maps of 1995/96 at East Hemel field indicated that 26.73%, 35.44%, and 37.62% of total area are covered by AZ and ±1, or > ±2 P off-take classes differed from AZ respectively (Table 2).

A difference map was constructed by subtracting P off-take maps of 1995/96 at East Hemel field (Figures 1 and 2). This map was classified based on the differences of P off-takes from 0.0 (Figure 3).

Table 1- Calculating agreement zones of P off-takes in 1995 and 1996 at East Hemel field

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Zones: 1996 P kg/ha 1995	Z1 = < 50 m² %	Z2 = (50 - 55) m² %	Z3 = (55 - 60) m² %	Z4 = > 60 m² %	Total 1995 %	Ave. 1995 P: kg/ha
Z1 = < 50	9870 4.95	10528 5.28	12502 6.27	5922 2.97	19.47	42.35
Z2 =(50 - 55)	8554 4.29	12502 6.27	13160 6.6	9212 4.62	21.78	52.56
Z3 = (55-60)	17108 8.58	13818 6.73	17760 8.91	6580 3.30	27.52	57.61
Z4 = > 60	15792 7.92	14476 7.26	18424 9.24	13160 6.6	31.02	64.39
Total:1996	25.74	25.54	31.02	17.49	99.79	216.91
Ave. 1996 P: kg/ha	41.85	52.48	57.11	63.88	215.32	54.22 53.83

* Grid squares: 303 ** Grid area: 658 m^2 /square *** P: Phosphorus

Table 2- Comparing P off-take classes for maps of East Hemel between 1995/96

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Zones: Field:	*Agreement zone %*	*± 1 P off-take class %*	*> ±2 P off-take classes %*
1. East Hemel	26.73	35.44	37.62

The histogram of these differences indicates a normal distribution from hypo (-31 kg/ha) to hyper fertilised (48 kg/ha) areas in 1996 than 1995 within East Hemel field (Figure 4). 199 grid squares (~ 13 ha) in 1996 had P < ± 10 kg from calculated need.

The actual P off-takes of 1996 in each of the 303 grid squares of East Hemel field were subtracted from the mean of 1995 P off-take and mapped (Figure 5). This map was compared with map of Figure 3 to calculate the difference between them.

The new histogram is showing the difference between actual P off-take of 1996 and the mean of 1995 P off-take is more positively skewed than the histogram of Figure 4, 257 grid squares (~ 17 ha = 84.8% of total area) receive P < ± 10 kg from calculated need (Figure 6). This means that 58 grid squares (~ 4 ha of total area) more than difference map as shown in Figure 3 had P < ± 10 kg.

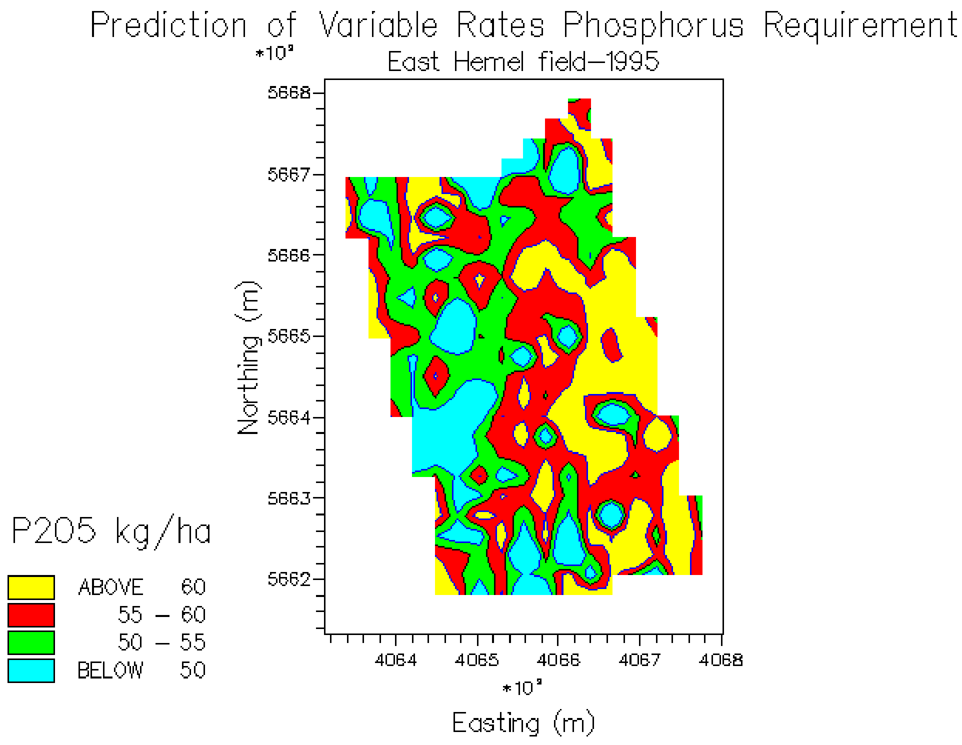

Figure 1- Map of P off-take -East Hemel field-1995

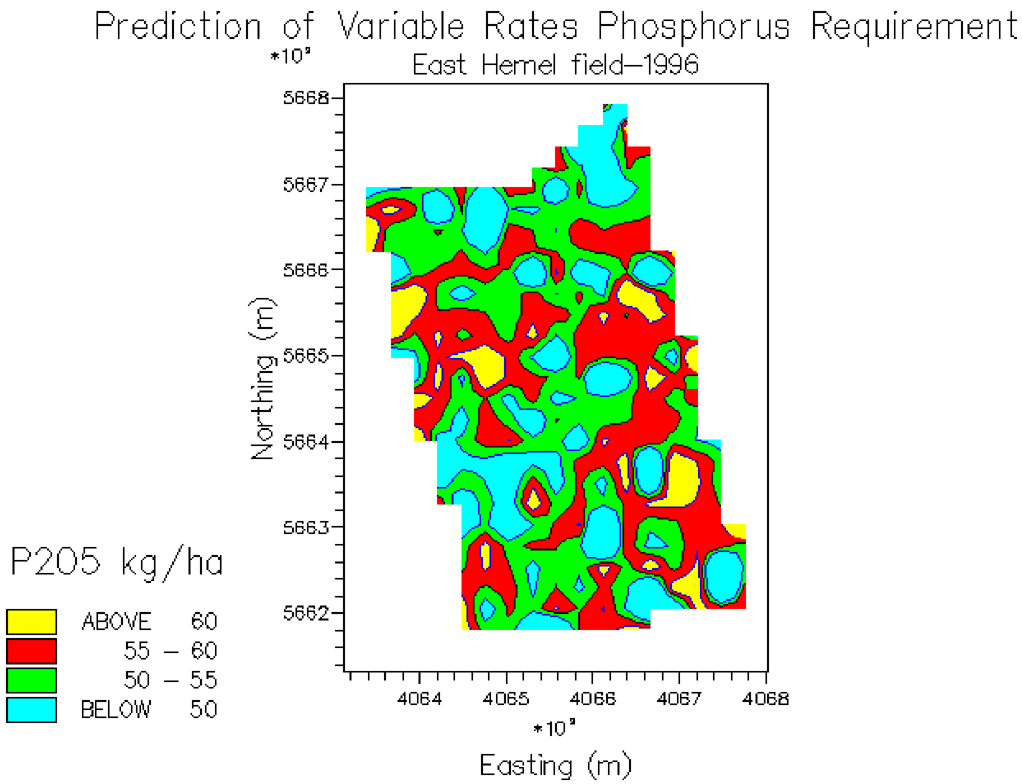

Figure 2- Map of P off-take -East Hemel field-1996

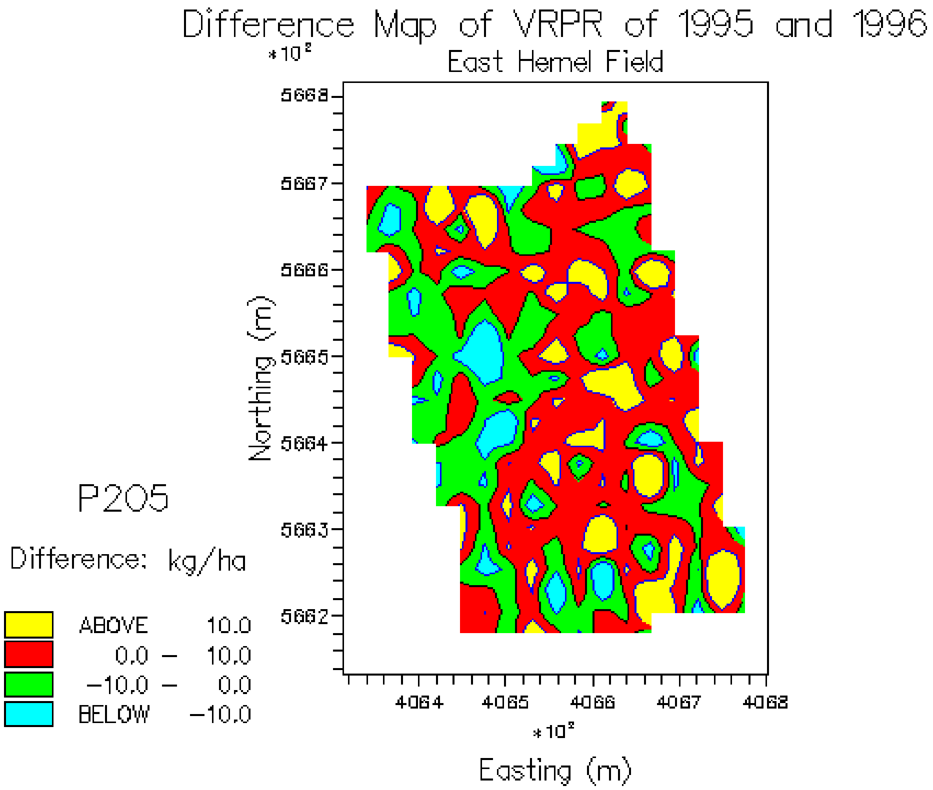

Figure 3- Map of subtracted 1995 P off-takes from 1996's

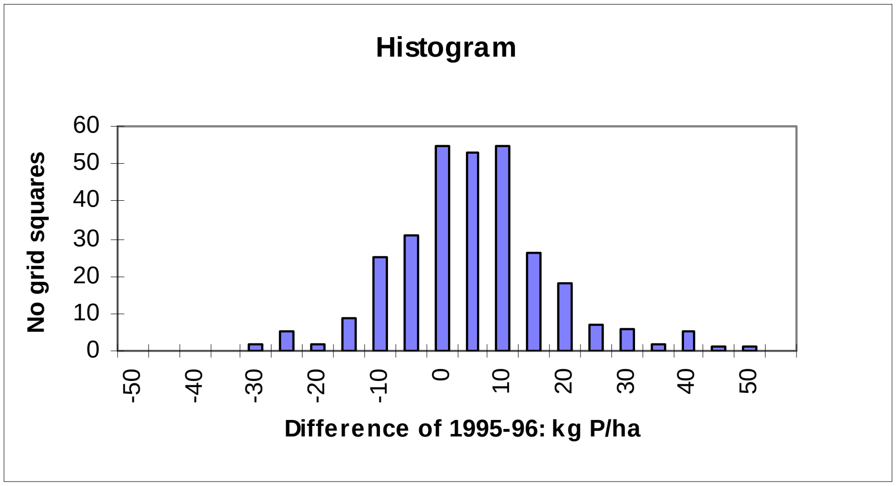

Figure 4- Distribution of subtracted P off-takes of 1995/96 in 303 grid squares of East Hemel

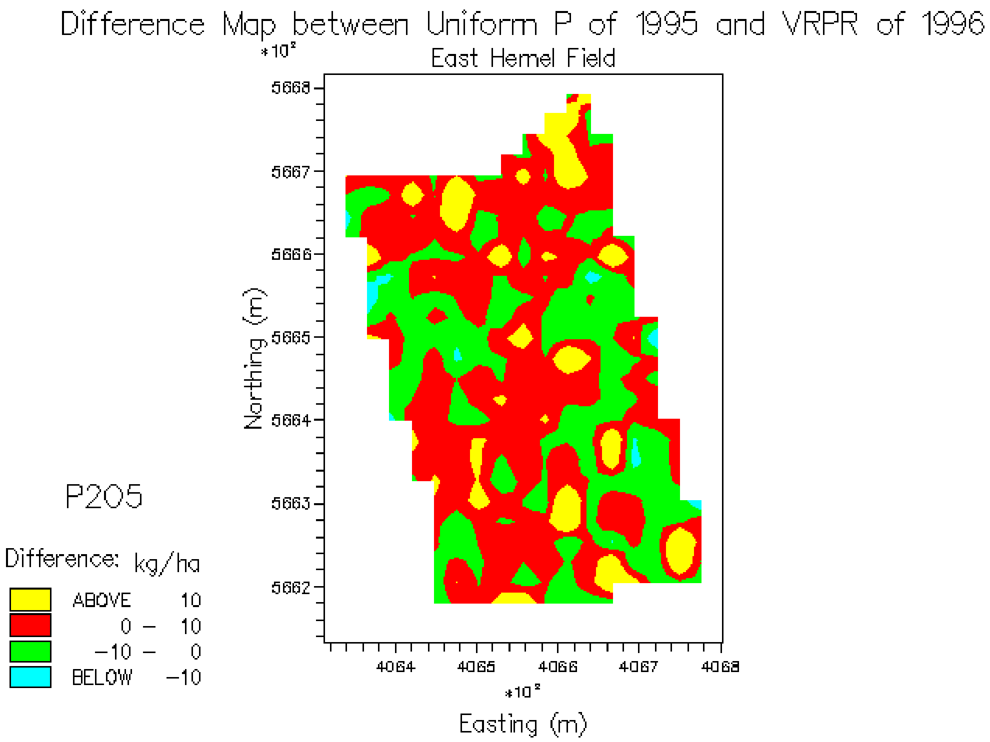

Figure 5- Map of 1996 P off-take after subtracting the average P off-take for 1995.

Comparing the two histograms (Figures 4 and 6) indicated that a substantial area is covered by P difference < ±10 kg/ha for both *uniform* and *variable rates* of P fertiliser planning which are very close to the calculated need (Table 3). However, a uniform P application shows less difference (% areas) for > ±10 P kg/ha. This means using a uniform P in this particular case is more satisfactory. Otherwise, P off-takes would be best synchronised with variable rates of P application (Figures 3 and 4).

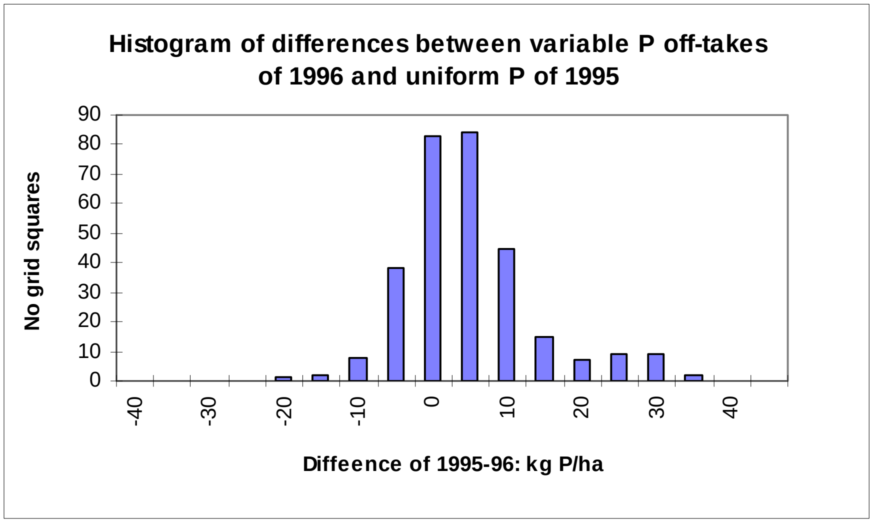

Figure 6- Distribution of subtracted P off-takes of 1996 in 303 grid squares from average Uniform P of 1995 at East Hemel field

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Table 3- % Area of East Hemel field with different P errors from two histograms.

P application: 1996	<-21 % Area	-11 to -20 % Area	-10 to - 0 % Area	+ 0 to +10 % Area	+11 to +20 % Area	>+21 % Area
Uniform	0.33	2.64	40.59	44.22	7.68	5.94
Variable	2.97	9.57	30.03	42.57	10.56	7.26
Difference:	-2.64	- 6.93	+10.56	+ 1.65	-2.88	-1.32

However, in this situation, because of very poor correlation of yield in 1995 and 1996, the previous year's yield does not provide a good prediction of next year's P maintenance application.

DISCUSSION FOR IMPLEMENTATION

The necessity of study for overall yield variability sources: To achieve more reality of the above mentioned idea, the next important step of executive functions must be study of both temporal and spatial yield variability sources that should be carried out in order to explain or interpret yield maps. The yield variation may be caused by spatial variability of soil fertility or its interaction with climate factors (Costigan et al., 1983), variation in slope, aspect and topographic shape (Larsen, 1986) and other features which were not investigated here.

Yield variation within and between the fields can be controlled by some limiting factors such as availability of soil nutrients (Brady, 1974). In conventional farming method, changing the dose of uniform fertiliser inputs (Gaulthney et al., 1988 & Tyler Ltd. Partnership, 1991) or applying a wide range of a single N fertiliser from year to year can also affect the yield variation within fields (Costigan et al., 1983 & Larson, 1986).

The variability of weather and different availability of soil water content and rain from year to year besides the other spatial variations across a field can be considered as the sources of yield variability. Factors such as soil nutrient availability, pH, soil organic matter, soil type and depth, soil properties such as texture (i.e. from sandy loam to heavy clay loam), soil compaction, drainage as well as agrochemical inputs can be considered as the main sources of yield variability.

These above parameters were not measured and considered in framework of this project. .However, a lot of works have been done by well known researchers due to determination of responsible sources for variation in yield across the field which is still a daunting task in each local situation. For instance, Mulla et al. (1992) studied some spatial patterns in properties affecting winter wheat grain yield variation and quality. They reported landscape position, soil profile available water content, residual soil N, soil test P levels, organic matter content, depth to root restricting layer, and soil series erosion phase as important yield variability sources. They emphasised that *soil profile available water content* and *organic matter content* showed the highest correlation to variations in yield which were controlled by landscape position.

In USA the differences in crop yield between poor and excellent climatic years may often be one order of magnitude (Mulla & Schepers, 1997 quoting Huggins & Alderfer, 1995). Hence, the interaction between regional excessive soil moisture and poor internal drainage with climate conditions of wet years in parts of landscape across the field can be responsible for planting delays, poor crop germination, poor soil aeration and soil compaction, nutrient deficiencies, and yield reductions.

Variation in soil texture also may influence crop growth within the field very differently in wet and dry years. For example, clay-rich areas may give better than average yields in dry years because of their better water retention, which in wet years these areas have low yields due to water-logging. Loamy sand soil has higher infiltration, drainage capacity, and better aeration than heavy clay (Bridggs & Courtney, 1991). In general, unlike the above discussion due to yield variability sources, it is not easy to qualify the overall impact of the factors involved to both temporal and spatial variability within each field.

To date, farming management decisions largely are focused on strategies for managing spatial variability in an average to good growing season climate, rather than managing of both spatial and temporal variability (Mulla & Schepers, 1997). Researchers have developed methods such as border-line analysis to evaluate a combination of spatial yield data with each yield variability source such as soil pH to find their relation for an optimised production (Schnug et al., 1993). However, both data of temporal and spatial yield variability sources such as field slopes, moisture availability, soil organic matter and texture, topsoil depth and so on must be analysed to explain in-field yield variability successfully (Miller & Veseth, 1993).

In author's opinion, the same above data analysis might be performed to identify the independent effect of each yield variability source such as soil moisture or pH. Hence, accurately maintaining the specific requirements of the crop (i.e. fertiliser input) for different soil conditions (i.e. soil fertility) of the smaller management units depends on reliable finding of local yield variation source. This helps to provide a practical map of variable rates application for each field treatment. <u>*So to optimise farm management, both temporal and spatial variability and their interactions with soil properties and crop yield should be taken into account*</u>. A wider range of in-field variability as experienced in some parts of this project increases the eligibility of the fields to be managed more precisely towards an optimisation.

Construction of a reliable yield map not only contribute to estimate the spatial yield patterns for a given year but their results are often thought to be important for delineating variations in yield goal throughout a field (Schnug et al., 1993). <u>*This requires several years' data analysis of in-field soil and crop variability to determine correlation between consistent low and high yield areas with major yield variability sources.*</u>

The in-field processes and properties, which show a significant correlation with crop yield variation, can be considered to reach an expected yield goal. For this, the key agro-technical limitations must also be identified to provide the optimum profitability and environmental protection for a successful precision farming management. In my opinion, probably the most important process that complicates the use of yield mapping for estimates of yield goals is temporal variability in measured yield. Hence, perhaps weather variability is no less important than in-field spatial variability while the impact of in-field spatial variability on crop yield may be negligible in some years (Mulla & Schepers, 1997).

ULTIMATE CONCLUSION

Limited practises by the author showed here, the potential of yield mapping to predict variable rate phosphorus application (VRPA) is that it integrates soil, landscape, crop and climate factors together into an expression of relative productivity as also Kitchen et. al. stated (1995). Therefore, if yield variation patterns within fields changed from year to year and from crop to crop, then yield mapping would offer little guidance for developing variable rate application (VRA) strategies. In confirmation of this, our findings showed that the correlation between two sets of regular yield data of 1995 and 1996 was not adequate to develop a VRP application other than to correct for variable off-take by the previous year's crop.

Hence, in this case the plan would be to restore fertility to a common base. If correlation was significant (i.e. ~ 0.5) then we could plan greater inputs for higher yield areas.

Ultimately, in order to develop plans for varying fertiliser rates, defining different management units from yield mapping should be done. For this, accumulation of several years (3-5) of data collection is required to avoid any confusion related to temporal or seasonal yield variability as above which probably requires more soil and climate data too.

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REFERENCES:

1. Brady, N. C. (1979). The Nature and Properties of Soils, 8th edition, pp: 19-21.UK.

2. Briggs, David J. and Courtney, Frank M. (1991). Agriculture and Environment: The Physical Geography of Temperate Agricultural Systems. Longman Scientific &Technical.

3. Costigan, P. A.; Greenwood, D. J. & Mcburney, T. (1983). Variation in Yield Between two Similar Sandy Loam Soils. I. Description of Soils and Measurement of Yield Differences. Journal of Soil Science, 34, 621-637.

4. Kitchen, N. R.; Hughes, D. F.; Sudduth, K. A. and Birrell, S. J. (1995). Comparison of Variable Rate to Single Rate Nitrogen Fertiliser Application. Corn Production and residual Soil $NO_3 - N$. Site-Specific Management for Agricultural Systems, American Society of Agronomy, pp. 251-271. USA.

5. MAFF (1994 & 1997). Fertiliser Recommendations. Reference Book 209, London, HMSO.

6. Miller, P. C. H. (1993). The Control Of A Spatially Variable Herbicide Sprayer. In SCI (Ed.), Sensing & Control Aspects Of Spatially Variable Field Operations, (pp. 14-15). London: SCI.

7. Mulla, D. J.; Bhatti, A. U.; Hammond, M. W. And Benson, J. A. (1992). A Comparison of Winter Wheat Yield and Quality under Uniform Versus Spatially Variable Fertiliser Management. Agriculture, Ecosystems and Environment 38: 301-311. USA.

8. Mulla, D. J. & Schepers, J. S. (1997). Key Processes and Properties for Site-Specific Soil and Crop Management. ASA-CSSA-SSSA, Madison, USA. The Site Specific Management for Agricultural Systems.

9. Sadler, E.; Bauer, P.J.; Busscher, W.J. (1995). Spatial Corn Yield During Drought in the SE Coastal Plain. ASA-CSSA-SSSA, Madison, USA.

10. Sanaei, A. & Yule, I. J. (1996b). Yield Measurement Reliability on Combine Harvesters. In ASAE (Ed.), ASAE Annual International Meeting, Paper No. 961020 (pp. 14). Phoenix Arizona: ASAE. USA.

11. Sanaei, A. & Yule, I. J. (1996a). Accuracy of Yield Mapping Systems: The Effects of Combine Harvester Performance. AgEng'96 Conference, Madrid, Paper 96G-016. Spain.

12. Sanaei, A. (1999). The Role of Yield Maps to Plan Fertiliser Inputs in Precision Agriculture. Proceeding of international Conference on Agricultural Engineering (99-ICAE), "Innovation of Agricultural Engineering Technologies for The 21st Century" (pp. V122), Beijing, P.R.China.

13. Schnug, E.; Murphy, D. and Evans E. (1993). Yield Mapping and Application of Yield Maps to Computer-Aided Local Resource Management. ASA-CSSA-SSSA, Madison, USA. Site-Specific Crop Management.

14. Vansichen, R. & De Baerdemaeker, J. (1991). Continuous Wheat Yield Measurement on a Combine. Automated Agriculture for the 21st Century, Michigan, ASAE, pp 346-455, USA.

15. Yule, I. J.; Sanaei, A.; Hodgkiss, A. & Korte, H. (1995). Yield Mapping Combinable Crops: Field Experience, Problems and Potential. International Agricultural and Biological Engineering Conference; New Horizons, New Challenges, 1 (pp. 2). University of Newcastle Upon Tyne. England.