POTENTIAL OF PRECISION FERTILIZATION OF FIELDS WITH P AND K BASED ON SPATIAL VARIATION IN NUTRIENT CONTENT AND CROP YIELD

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Different models used for calculating nutrient requirement were compared taking precision farming system as standard. Half of the field area received incorrect amount of fertilizer using conventional method whereas 20% improvement was observed in area correctly fertilized by using average yield and variable soil nutrient index method. Little more improvement in variable soil nutrient index and mean yield for each soil index method was noted than average yield and variable soil nutrient index method. However, even using the gridded (20 m x 20 m grid) precision farming system as standard compared with others, this system is not perfect. For P and K, the result of ignoring within-field variations is that high-yielding parts of the field are inadequately fertilized, while soil nutrients tend to accumulate in low-yielding areas.
Key words: Precision farming, Spatial variation, Soil nutrients, Crop yield

INTRODUCTION

Soil test results from the basis on which fertilizer needs determined. In the past, before fertilizer came into common usage, it was relatively uncommon to find big differences in nutrient levels in different parts of a given field, expect where extreme heterogeneity of soil type existed (Melsted and Peck, 1973). Today, large differences in nutrient levels are often found in samples taken from different parts of the same field. Calculations of nutrients removal by crops would also allow the amount lost to be replaced, but this assumes that the content in the soil is non-limiting. Yield variability within fields was demonstrated at an even earlier date, making it clear that the off take of nutrients and the maintenance replenishment, was certainly non-uniform (Mercer and Hall, 1911).

General lack of response to P and K in arable crops on many soils has encouraged use of fertilizer programmes based on maintenance applications of both P and K to replace the nutrients taken off by plants (Barraclough, 1993). This approach, however, does not take into consideration geographic variation in crop demand and soil availability, and can lead to localized over or under-application. Soil sampling and testing are commonly used to make recommendations on P_2O_5 and K_2O fertilizer rates (MAFF, 1994). The traditional practice is that a fertilizer recommendation is based upon the result from a single composite sample, and one uniform rate of fertilizer is applied over the whole field. Usually the samples, which make up the composite do not fairly cover the entire area and the result, therefore, may not be representative of the whole area. Even with intensive sampling, the overall mean, though probably a better estimate of the central tendency than a single composite sample, cannot account for variation of soil fertility within the field. In other words, the use of the field average would lead to inaccurate application, either too much or too little phosphate and potash, to portions of each field. Yield is treated uniformly, so that any fertilizer rate variation is traditionally based on field average yield. This will result in high yielding areas of the field receiving too little fertilizer. Local over-fertilization may deteriorate drainage water quality, reduce profit margins, induce deficiency of other elements and interfere with metabolic processes, while under-fertilization may restrict crop yield and quality. Variable rate application avoids these problems but requires knowledge of the scale of variability of soil and crop parameters within each field and whether this is random or patterned. In order to examine the improvements in nutrient use efficiency that can result from variable rate application, this study has been designed with the following specific objectives:

- Characterize the extent of spatial variability patterns in the field based on P and K soil contents.
- Calculate and compare the net returns averaged from uniform and variable rate application models and their effects on the crop yields.

Procedure for P and K requirement calculations

Intensive soil samples were taken from 8.2 ha field at Welton field, Nafferton farm, University of Newcastle upon Tyne, UK (54° 59′ N, 1° 54′ W) and at an elevation of 90 m above mean sea level; NZ 091641). Soil samples were spaced on approximately a 20 m x 40 m grid to provide relatively uniform coverage over the entire area. The exact locations of soil samples were determined using Differential Global Positioning System (DGPS). Crop was harvested using a Deutz Fahr combine harvester equipped with an RDS Ceres yield meter, Hermes data logging system with RDS moisture sensor and Navstar Differential Global Positioning System (DGPS). The ADIS (Agricultural Data Interchange Syntax) format was used (Yule *et al.*, 1995).

Yield and nutrient data were converted to a regular common spacing of 20 X 20 m^2 by interpolation using UNIRAS (1989). Nutrients maps were produced using UNIMAP (UNIRAS, 1989). The regular grid of soil and yield points were transferred to a spreadsheet and the amount of fertilizer to be applied to each grid square was calculated using the following strategies:

1. Whole field average yield and average soil index: The average soil nutrient index and yield were used for each field to calculate nutrient requirement.

2. Whole field average yield and variable soil: The average field yield was to calculate the maintenance application of nutrients and, based on MAFF (1994). 25 $kgha^{-1}$ was added if the soil nutrient index of the area was 1 and 50 $kgha^{-1}$ if the index was 0.

3. Variable soil and average yield for each soil nutrient index: The amount of nutrient in each area of the field was based on the soil index, as above, to which was added a maintenance amount based on the yield for that area.

4. Precision farming system: Precise fertilizer requirements for each grid square were calculated from the nutrient offtake based on interpolated yield and from the P and K index of the grid square and the resultant values were mapped. For cereals, the crop was assumed to have removed 7.5 g P_2O_5 and 5.6 K_2O per kilogram (MAFF, 1994).

RESULTS

The yield of crops (Table 1) varied widely within field in both years. The CVs are larger and yields are negatively skewed. Soil P and K contents were more variable (Table 1) and are well correlated in both years (r = 0.955 and 0.843 in 1996 and 1997 respectively). Yield correlated negatively in both seasons with soil P and K.

Table 1. Univariate statistics of soil available Phosphorus and Potassium (ppm)

Soil	Mean		Min-Max		SD		CV%		Skewness	
Property	1996	1997	1996	1997	1996	1997	1996	1997	1996	1997
P	13.8	15.5	4.4-34.8	5.2-42.7	6.9	8.19	49.9	52.7	1.35	1.27
K	84.1	106	42.9-198	34.2-253	37.4	54.06	44.5	51.2	1.14	0.89

Table 2. Summary of parameters for semivariograms of soil Phosphorus and Potassium (ppm)

Soil	Sill		Range (m)		Nugget		Nugget-to-Sill ratio	
Property	1996	1997	1996	1997	1996	1997	1996	1997
P	46.4	65.7	130	130	24	28	0.52	0.43
K	1370	2864	120	120	850	2100	0.62	0.73

The crop and soil variables had a large range, and the sills were substantially larger than the nuggets (Table 2). The mean soil P and K indices for the field are 1. The contour maps of the soil P and K concentrations show areas of low soil available P and K which need extra P and K fertiliser, and other areas sufficiently high in P and K where fertiliser is unnecessary (Fig. 1).

1. Conventional Method Based on the average soil index for P and K (1) and yield (7.3 t/ha for wheat and 8.24 t/ha for barley), 89 $kgha^{-1}$ of P_2O_5 and 109 $kgha^{-1}$ K_2O would be recommended for the wheat crop in 1996, and 96 $kgha^{-1}$ P_2O_5 and 117 $kgha^{-1}$ K_2O would be recommended for the barley crop in 1997 (MAFF, 1994).

2. Average Yield and Variable Soil Nutrient Index: Half of the total area is occupied by nutrient index 1, but one third is index 2 and the remainder index 0.

3. Variable Soil Nutrient Index and mean Yield for each Soil Nutrient Index: Using the average yield for each soil index, fertilizer requirement in index 0 areas is more than with the Average yield and variable soil nutrient index and Conventional method, because the yield in the index 0 area is more than the average for the whole field. Yield in index 2 areas was less than in index 0 and 1 areas in both years (Tables 3-6) and hence requirement of fertilizer P_2O_5 and K_2O was also less in index 2 areas than with the Conventional method and Average yield and variable soil nutrient index method (Tables 3-6); the differences are, however, small - less than 10 $kgha^{-1}$.

Table 3. Amount of P_2O_5 required in 1997 based on Conventional and Precision systems

Soil P	Area		Conventional		Equal yield and variable soil		Average yield for each Index & variable soil			Precision farming system		
Index	(ha)	(%)	P_2O_5 (kg/ha)	Total (Kg)	P_2O_5 (kg/ha)	Total (kg)	Yield (t/ha)	P_2O_5 (kg/h)	Total (kg)	Yield (t/ha)	P_2O_5 (kg/ha)	Total (kg)
0	1.12	16.4	89	100	114	128	7.78	118	132	5.2-10.6	96-143	132
1	4.40	64.3	89	393	89	393	7.50	91	399	3.7-8.9	57-103	395
2	1.32	19.3	89	118	64	85	6.44	56	74	2.5-8.8	22-77	74
Total				611		606			605			601

Table 4. Amount of P_2O_5 required in 1998 based on Conventional and Precision systems

Soil P	Area		Convential		Equal yield & variable soil		Average yield for each index & variable soil			Precision farming system		
Index	(ha)	(%)	P_2O_5 (kg/ha)	Total (kg)	P_2O_5 (kg/ha)	Total (kg)	Yield (t/ha)	P_2O_5 (kg/ha)	Total (kg)	Yield (t/ha)	P_2O_5 (kg/ha)	Total (kg)
0	1.04	15.2	97	101	122	127	8.58	125	130	6.4-11.9	103-154	130
1	3.16	46.2	97	307	97	307	8.38	98	310	6.3-10.8	80-120	307
2	2.64	38.6	97	256	72	190	7.77	68	179	4.0-9.9	18-87	179
Total				644		624			619			616

Table 5. Amount of K_2O required in 1997 based on Conventional and Precision systems

Soil K	Area		Conventional		Equal yield & variable soil		Average yield for each index & variable soil			Precision farming system		
Index	(ha)	(%)	K_2O (kg/ha)	Total (kg)	K_2O (kg/ha)	Total (kg)	Yield (t/ha)	K_2O (kg/ha)	Total (kg)	Yield (t/ha)	kg/ha	Total (kg)
0	1.72	25.2	109	187	133	228	7.74	137	236	5.2-10.6	109-170	236
1	4.64	67.8	109	504	109	504	7.31	107	496	3.7-9.2	67-129	493
2	0.48	7.0	109	52	83	40	6.30	71	34	2.5-8.8	28-99	34
Total				743		772			766			763

Table 6. Amount of K_2O required in 1998 based on Conventional and Precision systems

Soil K	Area		Conventional		Equal yield & variable soil		Average yield for each index & variable soil			Precision farming system		
index	(ha)	(%)	K_2O (kg/ha)	Total (kg)	K_2O (kg/ha)	Total (kg)	Yield (t/ha)	K_2O (kg/ha)	Total (kg)	Yield (t/ha)	K_2O (kg/ha)	Total (kg)
0	1.04	15.2	118	122	143	148	8.58	147	152	6.04-11	18-184	152
1	4.08	59.6	118	480	118	480	8.38	119	487	5.6-11.8	88-158	475
2	1.72	25.2	118	202	93	159	7.77	88	151	4.0-10.2	45-115	151
Total				804		787			790			778

4. Precision Farming System: The range of nutrients to be used was great within each soil index due to the variation of yield from cell to cell (Tables 3-6). As compared to Precision farming system, all the index 0 area is underfertilised in Conventional method and in index 2 all the area is overfertilised, while in index 1, 28 % is underfertilised and 40 % is overfertilised.

DISCUSSION

The most serious errors in applying nutrients using conventional method were under-application of P and K in the areas of index 0 and 1. The effect of underfertilisation would be to restrict growth and quality of the crop and this assumes that yield was not restricted by lack of nutrients, while in the overfertilised area there would be no immediate benefit for the crop, as well as possible luxury consumption of K in some cases and the possibility of risks of induced nutrient disorders (Shiel *et al.* 1997). Farmers frequently apply extra fertilizer to the crops as they recognise the use of greater fertilizer rates as a means of maintaining crop yield. However, this practice leads to considerable inefficiency of nutrient uptake and to enhance nutrient losses to the environment. Variable rate application of nutrients appears to be worthwhile and different models for calculating nutrient requirement are discussed in the following sections:

1. Conventional method

The uniform application of fertilizer only supplies an appropriate amount of nutrients to about half of the area within the field (Table 7), confirming the view of Shiel *et al.* (1997) that substantial areas of fields are currently underfertilised, while other areas are overfertilised, and that this is creating environmental and economic costs to the community and farmer respectively. Although not reported in temperate climates, P-induced Zn deficiency of winter wheat was reported by Singh *et al.* (1986). The application of excess phosphorus also decreased the concentration of Zn, Cu and Fe of barley plants (Singh *et al.*, 1995). The suggestion must be that non-uniform application should become common practice.

2. Average yield and Variable soil nutrient index method

Taking the Precision farming system as a standard, Average yield and Variable soil nutrient index method improved the appropriateness of nutrient application in 20 % more of the field relative to the Conventional method (Table 7).

because local under-and overfertilisation caused by the Conventional method in index 0 and 2 areas of the field respectively, may be reduced. These results of this study also suggest that where yield mapping technology is not available, the Average yield and Variable soil method is better than the conventional approach.

3. Variable soil nutrient index and mean yield for each soil index

There was little more improvement in the appropriateness of nutrient application using mean yield for each soil index method than Average yield and variable soil method (Table 7), because in index 2, 10 kg ha^{-1} less fertilizer required in mean yield for each soil index method than Average yield and variable soil method, due to variation in yield of index 2 area (Tables 3-6). Substantial parts of index 2 area being low yielding also means less off-take of nutrients, would result in accumulation of nutrients (Figure 2). It suggests that by applying low rates of nutrients in low productivity areas, the potential for contamination of surface and ground water is minimised. Therefore, Variable soil nutrient index and mean yield for each soil index is better than Conventional and Average yield and variable soil method.

4. Precision farming system

Although the Average yield and variable soil nutrient index and Variable soil nutrient index and mean yield for each soil index methods improved the appropriateness of nutrient application in 20 % more area of the field relative to the Conventional method, further improvement was obtained from correcting the

Table 7. Percentage of area receiving incorrect nutrient (P) using different models for calculating nutrient requirement as compared to precision farming system

Conventional method		Average yield and variable soil		Variable soil and mean yield for each index	
Nutrient error (kg)	Area %	Nutrient error	Area %	Nutrient error (kg)	Area %
< -50	3.5	< -25	4.0	< -25	1.8
-25 to -50	8.8	-10 to –25	9.9	-10 to -25	11.7
-10 to -25	11.7	10 to –10	71.9	10 to -10	72.5
10 to -10	51.5	10 to 25	13.5	10 to 25	13.5
10 to 25	13.5	>25	0.6	>25	0.6
25 to 50	10.5	-	-	-	-
> 50	0.6	-	-	-	-

Although in index 0 areas, the application of an extra 50 kg $P_2O_5ha^{-1}$ or K_2O is needed, the total fertilizer used is similar to that with the Conventional method because of the reduced fertilizer needed in the area of soil index 2. In index 2 area no fertilizer is needed except for maintenance (MAFF, 1994). There are economic as well as environmental benefits from use of this method as mentioned in the previous section, application rate on the basis of variation in crop yield in each cell. Once again there was little or no overall fertilizer savings related to the above mentioned methods. In the Variable soil nutrient index and mean yield for each soil index method a substantial area in each soil nutrient index is over- and under fertilized due to large variations in yield within each soil nutrient index (Table 7). Although possible, it is not currently practical to apply continuous varying amounts of

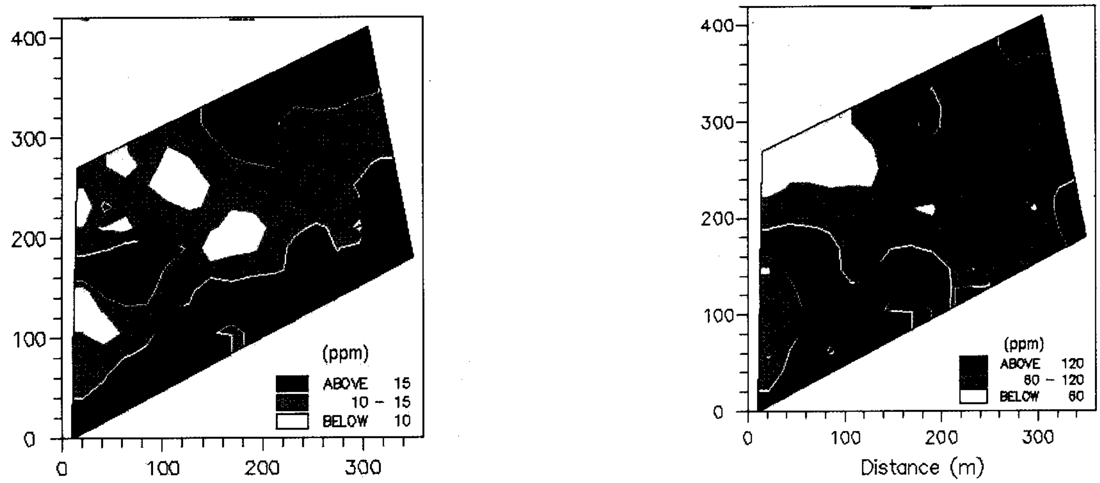

Figure 1: Contour maps of **P** (Right) and **K** (Left) based on concentration

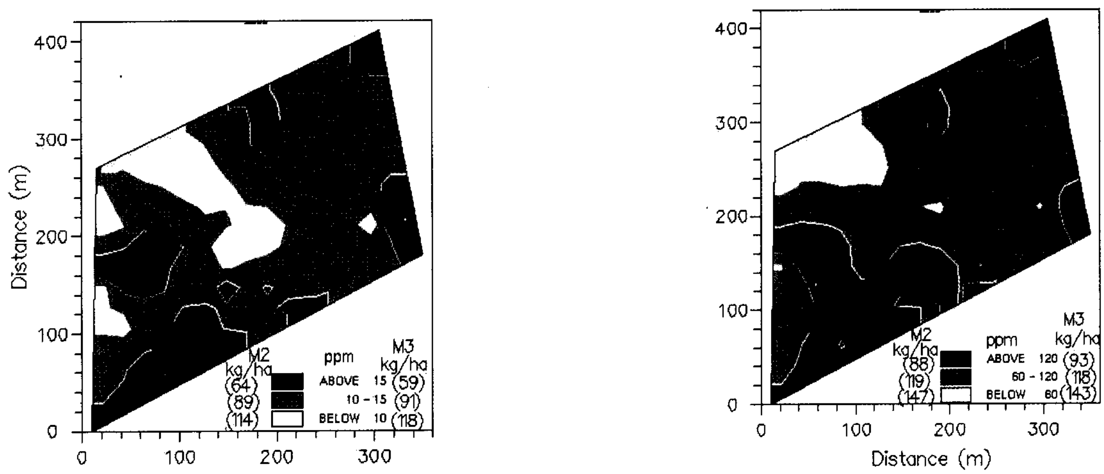

Figure 2: Contour maps of **P** (right) and **K** (left) requirements based on average yield and variable soil nutrient index (M2) and variable soil index and mean yield for each index methods (M3).

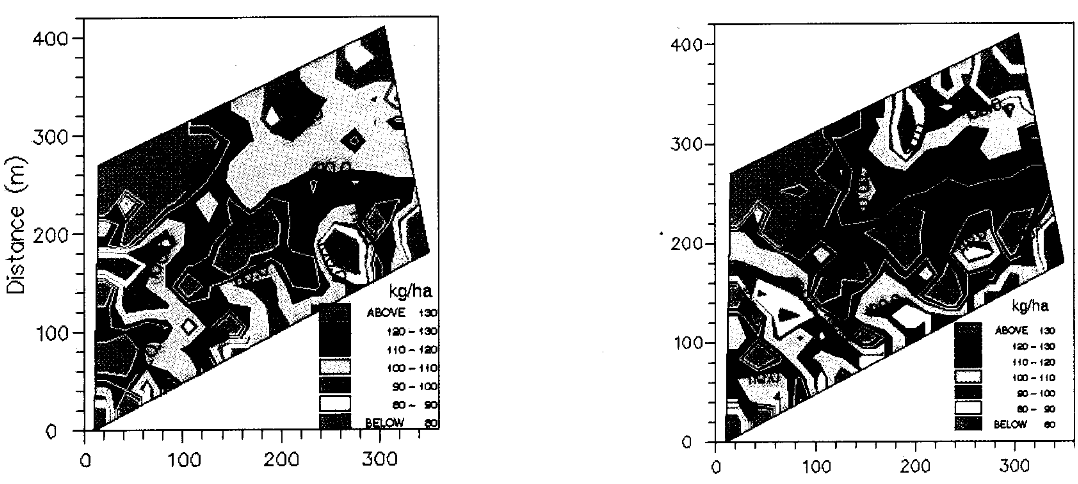

Figure 3: Contour maps of **P** (right) and **K** (left) requirement based on *precision farming system*

fertilizer across the field. In such a situation, the soil fertility could be best managed by dividing the field into sections (each section = ±10 $kgha^{-1}$ of nutrient), that are relatively homogeneous in soil available P or K levels and fertilising each portion according to its yield potential (Figures 3). It is clear that even using the gridded precision farming system as standard compared with others, this system is not perfect. The alternative, of using smooth contour boundaries has, however, been shown not to create larger improvements in efficiency (Shiel *et al.*, 1997). Closer sampling might improve accuracy, but there are limitations because of combine harvester yield-averaging (Sanaei, 1998) and also more soil samples produce relatively small change in map efficiency, for example, reducing the number of samples from 12.5 $samplesha^{-1}$ to 4 $samplesha^{-1}$ increased the error by only 15 percent or less using different interpolation methods (Mohamed, 1997).

CONCLUSION

As compared to the Precision farming system all the other systems would result in restricting growth and quality of the crop in potentially high yielding areas, while in the overfertilised low yielding areas there would be no immediate benefit for the crop, as well as possible luxury consumption of K in some cases and the possibility of risks of induced nutrient disorders and leaching of nutrient excesses.
The results of this study indicate that half of the field area would receive incorrect amount of fertilizer using the Conventional method, while there is 20 % more improvement by using Average yield and variable soil nutrient index and there is little more improvement in Variable soil nutrient index and mean yield for each soil index method than earlier methods as compared to Precision farming system.

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