HGCA

PROJECT REPORT No. 134

VARIATION WITHIN FIELDS OF POTENTIALLY AVAILABLE SOIL NITROGEN USING THE HOT KCl TECHNIQUE

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by

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Contents

Abstract

In February 1996, ten fields in the Lothians were chosen which had been ploughed but not yet sown with spring barley. They were sampled on a 30 metre grid and potentially available nitrogen (PAN) was measured by extraction with hot potassium chloride solution.

Differences between fields accounted for 72% of the sums of squares for differences in PAN and only 28% of the sums of squares was contributed by differences within fields. The field means ranged from 52 to 101 kg N/ha and the standard deviation of samples within the same field from 4.9 to 17.1 kg/ha. Some fields had well defined spatial trends but for other fields, the measured values appeared to be randomly distributed. Contour maps were drawn for all fields but may be of limited value for the fields without pronounced trends.

Simulated sampling within each field showed that the classic W-shaped sampling route with 8 or 16 sampling points per field gave values within 2 kg/ha of the field mean and was greatly superior to either of the two diagonal simulated sampling routes. Simulated effects of spatially -variable application of nitrogen fertiliser showed that this was unlikely to give sufficient benefits to justify the cost of multiple samples, even in the most variable of these fields. Uniform application to whole fields as indicated by a composite field sample and compared with a single nitrogen rate for all low N status spring barley fields, could however give benefits to the farmer up to £32/ha which would offset the cost of sampling and analysis. In addition, there might be a reduction in nitrate leaching of up to 9%.

Introduction

The hot KCl extraction method of Gianello and Bremner (1986) was found by McTaggart and Smith (1992 and 1993) to give a good correlation with uptake of soil nitrogen by spring barley in HGCA-funded Scottish trials with 15N labelled fertiliser nitrogen between 1987 and 1990, provided that the previous crop was a cereal. Since then SAC have been offering the test on a limited basis. It has been used mainly as an aid to achieving low grain nitrogen contents for traditional malting outlets, rather than as a means of achieving optimum yields. In the wet northern climate and on the sandy loams where Scottish malting barley is mainly grown, soil mineral nitrogen in the spring is usually very low. However, subsequent mineralisation is important. In the Scottish study, soil-derived nitrogen was responsible for an average of 50% of the total nitrogen uptake at normal fertiliser rates with a range from 35 to 63% (McTaggart and Smith, 1992).

Existing nitrogen fertiliser recommendations are based largely on previous cropping and take little note of soil type or organic matter content (Dyson, 1993). Experience from trimming inputs in the LINK Integrated Farming Systems (HGCA Project no. 0068/1/91) and the associated HGCA-funded small plot validation trials (HGCA Project no. 0012/01/93B) has shown that existing nitrogen fertiliser recommendations for spring barley and winter wheat have been on the low side. Attempting to cut them even more as a result of high soil mineral N values has tended to be unprofitable. We have consistently seen economic responses to an extra 30 or 40 kg N/ha above the chosen integrated treatment. This contrasts with the position for fungicide and herbicide where the low inputs used in the integrated system have generally proved profitable. Anything, therefore, that can assist in the prediction of nitrogen response is greatly to be desired.

The major uncertainty is the amount of mineral N which will be released during the period from mid-April when soil temperatures reach the critical 6°C until anything from 80 to 120 days after sowing (early June until mid July) when uptake by the barley ceases in Scotland (McTaggart and Smith, 1992). There is a weather element which may always be impossible to predict at the time the fertiliser must be applied; warm moist soils will mineralise more nitrogen than cold or dry soils. However, there is a soil element which is currently imperfectly predicted by previous cropping. We may never be able to compensate for the seasonal effect on nitrogen response and grain nitrogen content but we should be able to identify those fields which in any one season will need either more or less fertiliser nitrogen than the average.

An advantage of being dependent on potentially mineralisable nitrogen rather than carry-over mineral nitrogen from the previous year is that most of the organic matter that can mineralise is to be found in the plough layer. Deep sampling is not therefore required.

The objectives of this project were:

* to provide a guide on the best sampling protocol for those farmers who might wish to use the test for modifying the fertiliser recommendation for the whole field
* to make it possible to examine the likely returns to spatially variable N fertiliser application.

Materials and methods

All fields had a cereal as the previous crop and none had been in grass in the recent past (Table 1). The soils were sampled between 13 February and 27 February 1996. The fields had all been ploughed but no secondary tillage had taken place at the time of sampling. A baseline was marked along the straightest edge of the field and 15 metres in from the edge of the plough. Sampling points were marked off at 30 m intervals along this baseline. Perpendiculars were constructed from the baseline at each sampling point and sampling points marked at 30 m intervals along each perpendicular. At each sampling point, 20 trowel-samples to the full depth of the furrow were taken from a circle of about 2 m radius around the sampling point. These were bulked and mixed into a composite sample from which a subsample was taken. The final sample was labelled with the field number and location on the grid and then frozen within four hours of sampling.

Table 1. Details of the ten fields sampled for potentially available nitrogen in February 1996.

Field no	Farm name	Field name	Date sampled	Grid ref.	Previous crops 95 94 93 92
1	Mortonhall	Mid-Park	13 Feb	NT258682	WW WO WB WW
2	Herdmanston	Stackyard	20 Feb	NT478698	WW P SB SB
3	Luffness Mains	Parks	22 Feb	NT490801	WW P SW Sw
4	West Fenton	Fisher's Neuk	19 Feb	NT493812	SB SB WW WW
5	Pitcox	East Grindons	20 Feb	NT653758	SB
6	Remote	Cottage	21 Feb	NT403652	SB SB WW WW
7	Dodridge	33 acre	26,27	NT417651	SB WW SB SB
8	West Edge	Kilns	23 Feb	NT278673	SB WOR SB SB
9	Niddry Mains	The Siding	22 Feb	NT092758	WW WW WOR WB
10	Turniedykes	Richardsons Rig	16 Feb	NT388636	WW RSA WW WOR

WW = winter wheat, WB = winter barley, WO = winter oats, WOR = winter oilseed rape
SW = spring wheat, SB = spring barley, P = potatoes, Sw = swedes
RSA = rotational set-aside.

In the laboratory, 12 g of wet, thawed soil were refluxed with 80 ml of 2M KCl for four hours. After cooling, the suspension was filtered through Whatman No 42 paper and the extract analysed for ammonium and nitrate N by continuous flow analysis.

After extraction with hot KCl, the nitrate fraction approximates to the mineral nitrogen at the time of sampling and the much greater ammonium fraction gives an estimate of nitrogen to be found in the more labile fraction of the soil microbial and organic matter and likely to become available during the lifetime of the crop. In Tables 2 and 3 below, the two fractions expressed in mg/kg have been added together and multiplied by 2.4 to give an estimate of potentially available N (PAN) in kg/ha. This assumes a plough layer of 200 mm and a dry soil bulk density of 1.2 g/ml.

As a measure of systematic variation across the field, the PAN values were regressed against coordinates of the sampling point in the field:

$$PAN = a + b_1*i + b_2*i^2 + b_3*j + b_4*j^2 + b_5*i*j$$

where i and j are the distances from the starting point of sampling along perpendicular axes and in units of 30 m.

The percentage of variation accounted for by the regression (r squared) was calculated as an estimate of spatially systematic variation. Another approach to analysing the spatial variability was to calculate a smoothed PAN value at point i, j in the field by a weighted mean of all field values where each is weighted by w where:

$$w = 1/(d+1)^2$$

where d is the distance of the point from each sample measured in units of the sampling grid (1 unit = 30 metres). Thus for its contribution to the weighted mean at a sampling point, the measured sample has d=0, w=1, values one grid unit removed (d=1) are weighted at 0.25, two grid units (d=2) are weighted at 0.111 and so on. Distances not on a grid line are given by Pythagoras' theorem.

The following sampling methods were simulated by taking the geographically nearest sampling point to the point required by the choice of sampling route:

* 8 samples from the classic W sampling route through the field
* 16 samples from the classic W sampling route
* 8 samples from the longest diagonal of the field
* 8 samples, 4 from each diagonal

In each case the sample mean from the simulated route was compared with the mean of all samples.

Variable application of nitrogen was simulated by assuming that the sample at the centre defines a 30 x 30 m (0.09 ha) square for which the optimum fertiliser can be applied because the soil N status in known. For the non-variable comparison, optimum fertiliser applied is defined by the average conditions for the field but that the following responses occur from the incorrect application in each square:

	Below optimum	Above optimum
Yield	Reduced by 8 kg grain dry matter per kg N shortfall below optimum	Unchanged from optimum (ie plateau in linear-plateau model)
Grain nitrogen content	Reduced by 0.001% per kg N below the optimum N	Raised by 0.004% per kg above the optimum
Residual soil nitrate N, ie leachable N	150 g N for each kg fertiliser N applied up to the optimum	150 g per kg up to optimum plus 600 g N per kg fertiliser N above the optimum.

These are shown in Fig 1 and are based on SAC trials. If anything, they favour the variable application in the comparison by exaggerating the difference in slope of the response either side of the optimum.

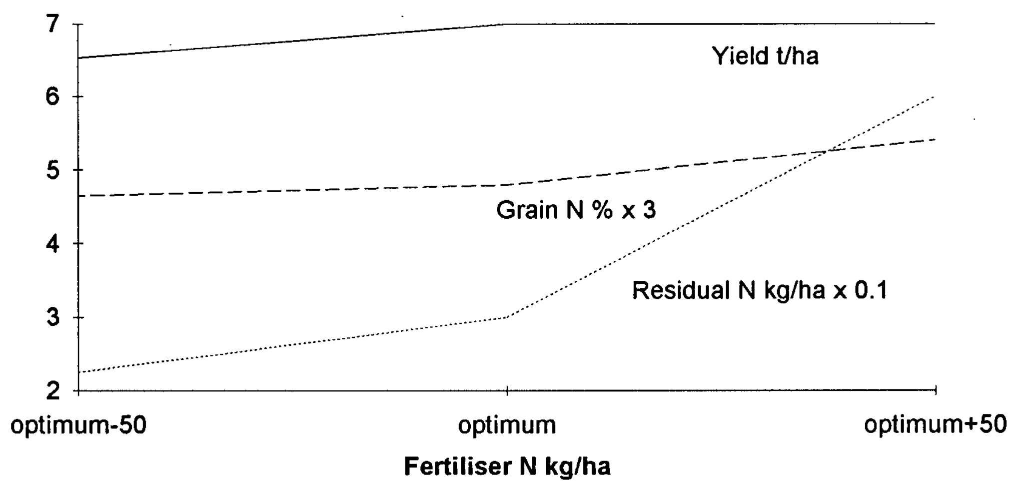

Figure 1. Assumed relationship of yield, grain nitrogen and soil nitrate residue to fertiliser nitrogen applied.

Results.

Variation and spatial trends:

The values of potentially available soil N, laid out as sampled in the field are given in Appendix 2 and the statistical properties of the ten fields are shown in Table 2. Sample values varied from 43 to 146 kg N/ha and the field means from 52 to 101 kg N/ha. Analysis of variance showed that 71.6% of the total variation was attributable to that between fields whereas only 28.4% was due to differences between samples within fields. The standard error of the field differences was 17.7 kg/ha and the pooled standard deviation for sample differences within fields was 10.1 kg/ha. Field 5 was the least variable with a range of 20 and standard deviation of 4.9 kg/ha and field 9 was most variable with a range of 76 and standard deviation of 17.1 kg/ha.

Fields with two cereals in the last four years averaged 69 kg PAN/ha, fields with three cereals averaged 79 kg/ha and fields with four cereals 84 kg/ha. The field with potatoes and swedes in the last four years averaged only 61 kg PAN/ha and was the second lowest in rank.

Four of the fields had variation that was reasonably systematic with more than 40% of the variation explained by the spatial regression. It is valid and fairly straightforward to draw contours for these and contours based on the regression agree quite well with contours based on the smoothing technique by weighted mean. The sample point smoothed values are given in Appendix 3.

The standard deviation of the smoothed PAN values ranged from 1.16 to 8.93 kg/ha. The smoothing technique has been preferred to regression for drawing contours because it makes fewer assumptions about the PAN gradients within the field. For fields with smoothed standard deviations in excess of 2.0 kg/ha, it is not difficult to draw and interpret contours but for fields 5 and 7, it is possible that the variation is entirely random and the contours have little meaning.

Table 2. Summary of the potentially available nitrogen in kg/ha for 30m grid samples from ten spring barley fields.

Field No.	Mean kg/ha	Range kg/ha	Standard deviation kg/ha	Coefficient of variation %	Regression on spatial co-ordinates F value	r squared %	Standard deviation of smoothed values kg/ha
1	99.2	61-139	13.7	13.8	7.09	56	5.68
2	61.7	48- 85	7.3	11.8	19.54	56	2.51
3	61.2	44- 72	5.7	9.3	5.14	33	2.02
4	78.4	61- 99	10.1	12.9	6.51	44	3.53
5	52.1	41- 61	4.9	9.4	1.55	14	1.16
6	94.4	59-130	14.8	15.7	3.08	23	5.53
7	58.2	43- 92	5.8	10.0	3.93	13	1.62
8	73.4	43- 96	9.9	13.5	1.75	22	2.82
9	100.9	69-146	17.1	17.0	5.64	40	8.93
10	76.4	54-131	12.0	15.7	5.08	27	4.02

Analysis of variance:

Source	Sum of squares	Sum of squares as %	Degrees of freedom	Mean square
Between fields	160 549	71.6	9	17 839
Samples within fields	63 584	28.4	620	103.6
Total	224 133	100	629	356.3

Contour maps of smoothed PAN values:

These are shown in Appendix 1. Field 1 had a strong diagonal trend with smoothed values less than 90 kg/ha of PAN in the north east corner rising to more than 110 kg/ha in the south west corner. Field 2 had a low point of less than 60 kg/ha in midfield with higher values along the south and south west boundaries. Field 3 had values lower than 60 kg/ha in the north east half of the field, except the extreme corner, values greater than 60 kg/ha in the north west and a high point in the southern corner. Field 4 had a diagonal trend from less than 75 kg/ha in the north west to 85 kg/ha at the south east extreme but with a short trough running in from the eastern boundary. Field 5, the most uniform but second least systematic of all fields, may have had a ridge of values greater than 52 kg/ha running from the south west boundary through the centre of the field and out toward the northern and eastern corners with troughs of less than 52 kg/ha adjoining the north west, north east and south east boundaries. Field 6 had values higher than 100 kg/ha in the middle of the field falling gradually to the west and south but rapidly to less than 85 kg/ha in the eastern extension of the field. Field 7 had least systematic variation but may have had a trough of less than 55 kg/ha toward but not at the northern corner and a ridge of more than 60 kg/ha at the eastern end of the south east boundary. Field 8 had values less than 75 kg ha from north west to south east boundaries and right through the middle of the field but with higher values along most of the north east boundary and at the western corner. Field 9 had a marked gradient from less than 90 kg/ha in the westward extension of the field to more than 110 kg/ha along the south east boundary of the wider part of the field but a very complex pattern into the eastern extension, though generally in the range of 105-110 kg/ha. Field 10 had values less than 70 kg/ha in the south east corner rising to more then 80 kg/ha along the western boundary and with a ridge of up to 85 kg/ha jutting in from the northern boundary and troughs of less than 75 kg/ha from the southern boundary.

Simulated sampling:

The W-shaped sampling route was far superior to either diagonal sampling route in both fields and overall (Table 3). There was little extra precision to be gained by bulking 16 samples on the W route compared with 8. Both were within 2 kg/ha of the "true" mean of all samples which is well within the application error for fertiliser.

Simulated spatially-variable application:

The simulation assumes a linear relationship between the test value and the fertiliser applied to each 30 x 30 m square in the variable application (1 kg of fertiliser N replacing 1 kg PAN was used but other substitution rates would be possible). There was, therefore, no difference in the total fertiliser applied to each field between variable and uniform application. Because the yield is simulated at the point at which the response to nitrogen becomes horizontal, the yield from the whole field is necessarily higher from variable application and ranged from 20 to 65 kg/ha, averaging 37 kg/ha of grain at 15% moisture over all ten fields (table 4). The grain nitrogen was necessarily reduced by variable application because the slope of the response is assumed higher above the optimum than below it. The difference varied from 0.006% to 0.021% and averaged 0.012% over the ten fields. The simulated residual nitrate nitrogen subject to leaching was raised by between 0.9 and 3.1 kg N per ha and averaged 1.8 kg N/ha over all ten fields.

Table 3. Estimates of mean values of samples bulked from different sampling routes simulated across the fields.

Field No.	"True" mean	"W" sampling routes 8 samples	"W" sampling routes 16 samples	Diagonal sampling routes One diag. 8 samples	Diagonal sampling routes Two diags. 2 x 4 samples
1	99.2	100.5	100.1	96.9	100.8
2	61.7	61.5	63.3	61.0	61.6
3	61.2	60.4	62.0	60.9	59.3
4	78.4	79.2	77.4	80.3	78.3
5	52.1	53.7	51.5	55.6	53.0
6	94.4	95.5	92.2	104.2	100.0
7	58.7	58.2	57.6	57.2	55.7
8	73.4	76.0	73.4	74.7	73.8
9	100.9	105.0	104.4	105.9	105.9
10	76.4	74.7	73.9	76.2	81.2
Root mean square deviation from "true" mean		1.83	1.73	3.85	3.11

Table 4. The effect of variable application on simulated yields, simulated grain nitrogen content and simulated residual soil nitrate nitrogen in the ten fields.

Field no.	Increase in yield kg/ha at 15% moisture	Decrease in grain N content %	Decrease in residual soil nitrate N kg/ha
1	45	0.014	2.1
2	27	0.009	1.3
3	21	0.007	1.0
4	39	0.012	1.8
5	20	0.006	0.9
6	56	0.018	2.7
7	20	0.006	0.9
8	36	0.011	1.7
9	65	0.021	3.1
10	43	0.014	2.0
Mean of all fields	37.2	0.012	1.8
Effect of uniform application to fields, compared with one rate for all fields	67	0.021	3.2

On the same assumptions we can compare the effect of varying the fertiliser nitrogen between but not within fields according to the test values. The comparison is with one fertiliser rate for all fields. Over all ten fields, the mean yield was raised by 67 kg/ha of grain at 15% moisture, the grain nitrogen content was reduced by 0.021% and the contribution to leaching was raised by 3.2 kg N/ha.

Discussion

All the fields had a cereal crop in the previous year and no recent grass in the rotation. They would be considered as low N status in Scotland, and N index 0 on the ADAS scale. Those with one or more non-cereal crops in the last four years tended to have lower field means for PAN but the differences were not large and it is probably best to conclude that previous cropping is not a useful predictor of potentially available nitrogen for fields classified as low N status.

If the test is a better guide to soil nitrogen status than the previous cropping, then the fact that there was more variation between fields than within fields in this study suggests that there are benefits to be gained by testing fields and then applying nitrogen uniformly over the field. Even for differences between fields, the benefits are not great:

* less than 0.1 tonnes/ha of yield
* improvement (reduction) in grain nitrogen content of about 0.02% when a typical range of values of in any one year is about 0.3%
* a reduction in the residual nitrogen at risk from leaching of the order of 3 kg/ha or 9% of the total simulated leachable N.

However, over the Scottish area of about 125 thousand hectares of spring malting barley the figures for uniform application to fields at the bottom of table 4 translate into an increased production of about 8 000 tonnes worth at least £1 million and a small improvement in quality. Allowing £15/tonne per 0.1% reduction in grain N%, the combined effect of the improvement in yield and quality is about £32/ha or about £120 for a typical field. This would easily pay for the cost of sampling and testing the field.

For a single test per field, a composite sample made up by bulking smaller samples taken in a W-shaped and four-legged traverse of the field, exactly as currently recommended for sampling for pH and available P and K, is also the best approach to sampling for potentially available N. It is very much better than sampling on the diagonals.

The PAN in some fields varied reasonably systematically across the sampled area and for these fields contours of PAN could be drawn and easily interpreted using either fitted values from spatial regressions or smoothed values. For fields with more random variation, contours were drawn but were not always easy to interpret. Three components of variability could be present in theory:

* trends across fields
* clusters of high or low values not associated with trends
* sample variation.

More could perhaps be done with these data to distinguish between these three components of variability but intuitively, the third appears to have accounted for at least 50% of the variation even in the fields where variation was most systematic. Although contour maps may be drawn and used to control spatially variable application, the improvement in precision may be largely illusory except where there are strong trends across fields.

Leaving aside problems of variability, the simulation exercise suggests that the benefits from the use of multiple soil tests for potentially available nitrogen as a means of "precision farming" with varied fertiliser N application rates within the fields are small. This conclusion is dependent on the model used for relating yield and grain nitrogen content to total (soil + fertiliser) N. However curvilinear relationships such as the quadratic with gently changing slopes give even smaller simulated benefits from variable application. The assumptions have, in fact, been chosen to maximise the simulated effect of variable application by assuming that the slope of both yield and grain nitrogen content change abruptly at the point of economic optimum fertiliser N application (see Fig 1). Both systems assume perfect foreknowledge of that point: the variable system for each 30 x 30 m square and the uniform system for the whole field. This assumption is, of course, not realistic but building uncertainty of equal scale into both systems moves them both away from the point of changing slope and reduces the simulated advantage of variable application. The simulated benefits in table 4, whether for uniform application to whole fields or for variable application are therefore greater than are likely to be achieved in real farm practice.

For these fields, the improvement in output resulting from variable application and allowing for both yield and quality, is estimated at £18/ha. In the most variable field (no. 9), the estimated improvement is worth £31/ha. This would certainly not cover the cost of sampling and analysis, at least not at the intensity adopted here of about 11 sample points per hectare. Neither is the benefit to the environment from reduced leaching very great at 1.8 kg/ha less from variable application or about 6% of the potential leaching loss.

Conclusions

1. Differences between fields in potentially available (hot KCl soluble) nitrogen are of more importance than differences within fields.

2. For fields classified as low N status, previous cropping does not give further useful differentiation between fields for potentially available N.

3. In some fields there is a systematic trend across the field but this is certainly not true for all fields.

4. The conventional W-shaped, four-legged sampling traverse of the field recommended for routine sampling for pH, P and K is also appropriate for potentially available nitrogen.

5. The size of the estimated improvements in yield and quality (lower grain N content) available from whole-field sampling for potentially available nitrogen before spring barley is probably sufficient to justify the cost of sampling and analysis.

6. There is also a small environmental benefit from reduced nitrate leaching estimated at 9% of that which occurs when fertiliser recommendations are made with no knowledge of potentially available nitrogen.

7. The size of the additional improvements from variable application within fields (precision farming) was nowhere near sufficient to justify the cost of taking and analysing multiple samples from any of the fields in this study.

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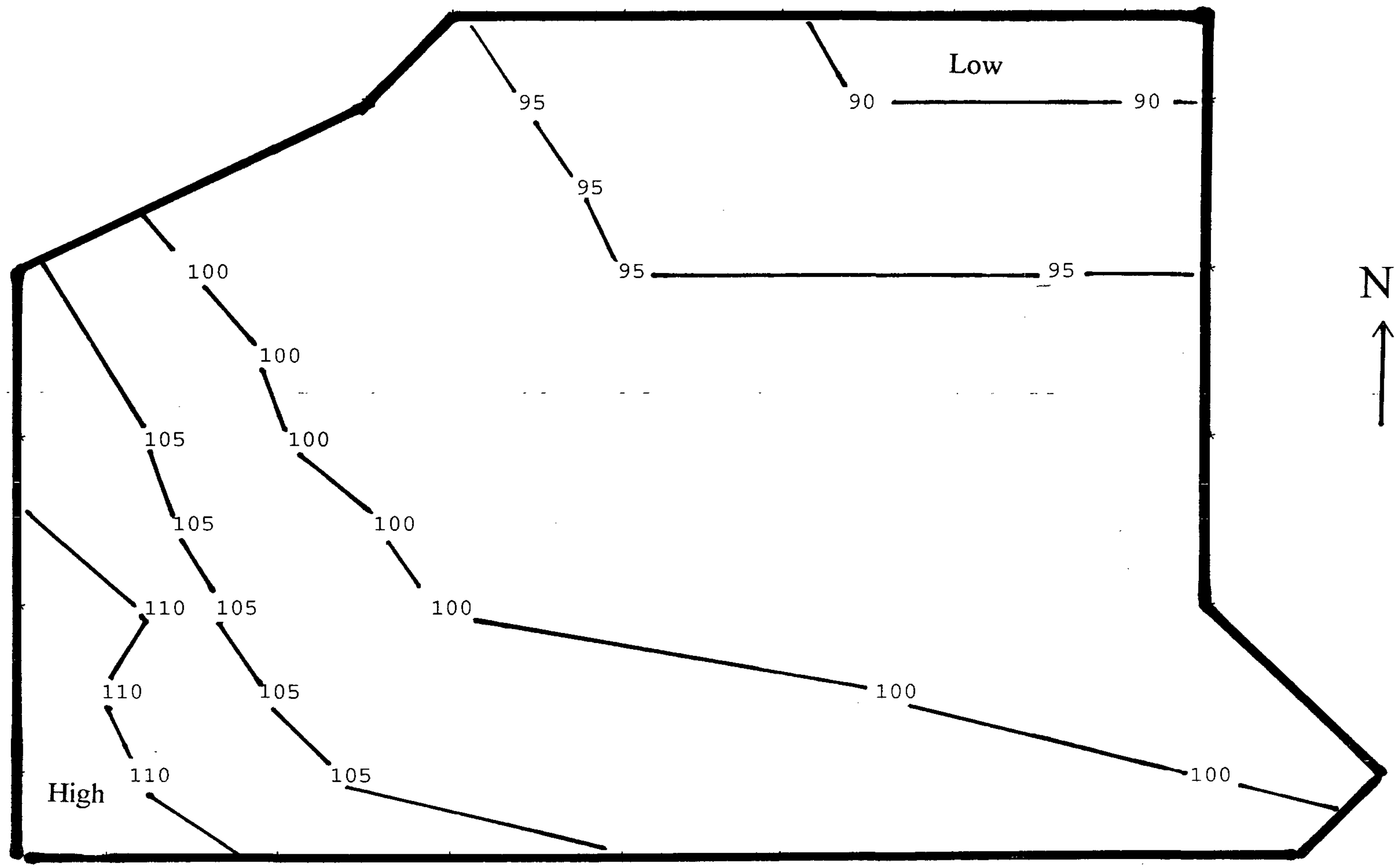
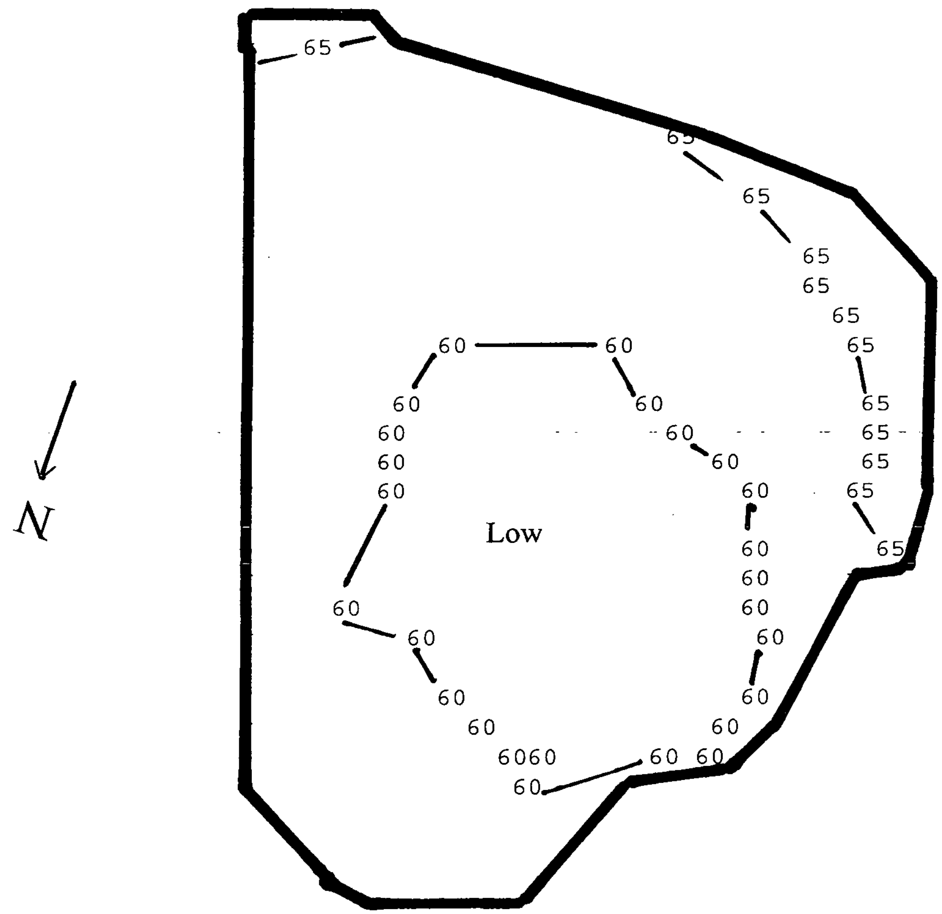
Appendix 1.

Contour maps of the sampled fields

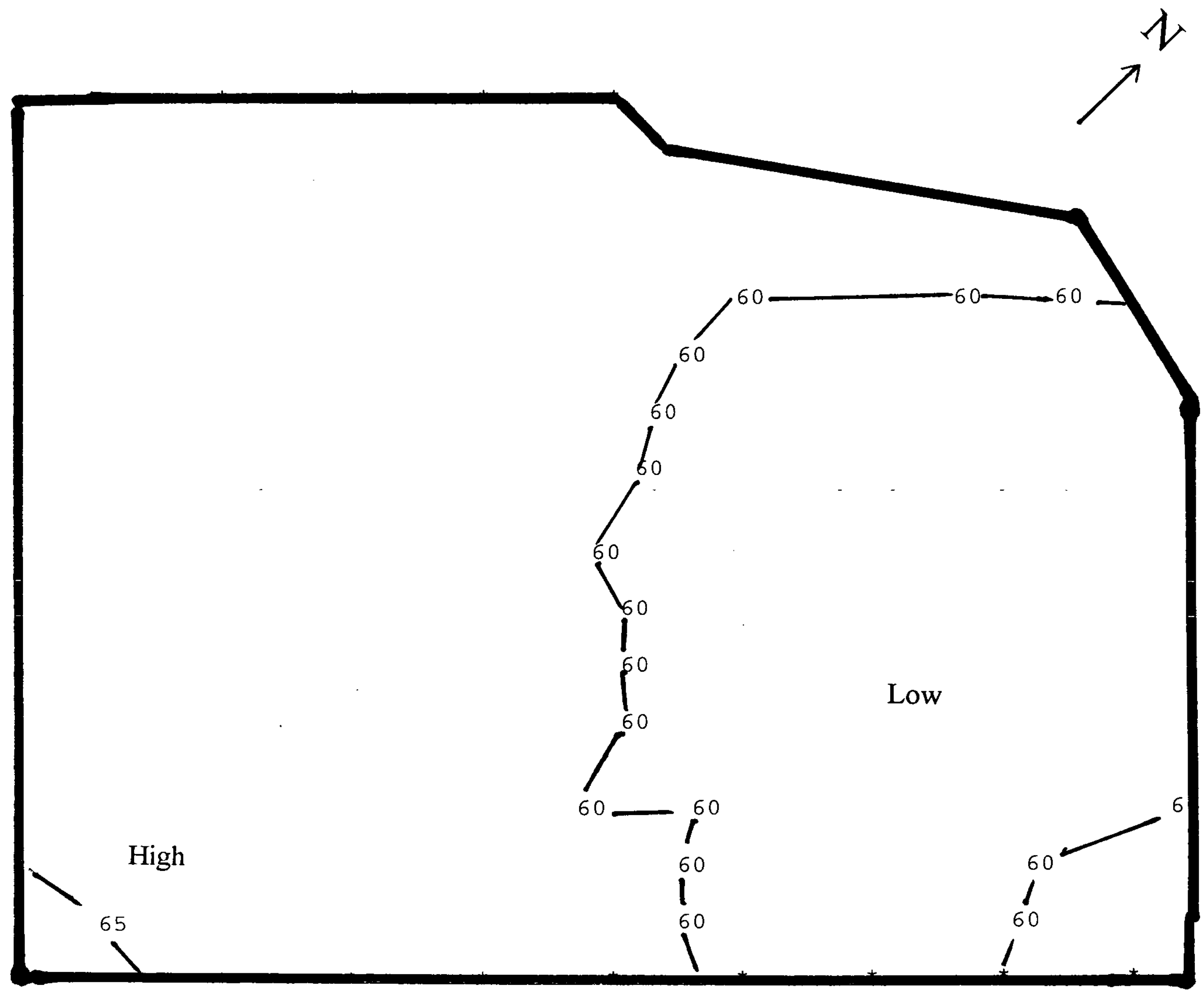
Field no: 1 Farm name: Mortonhall Field name: Mid Park



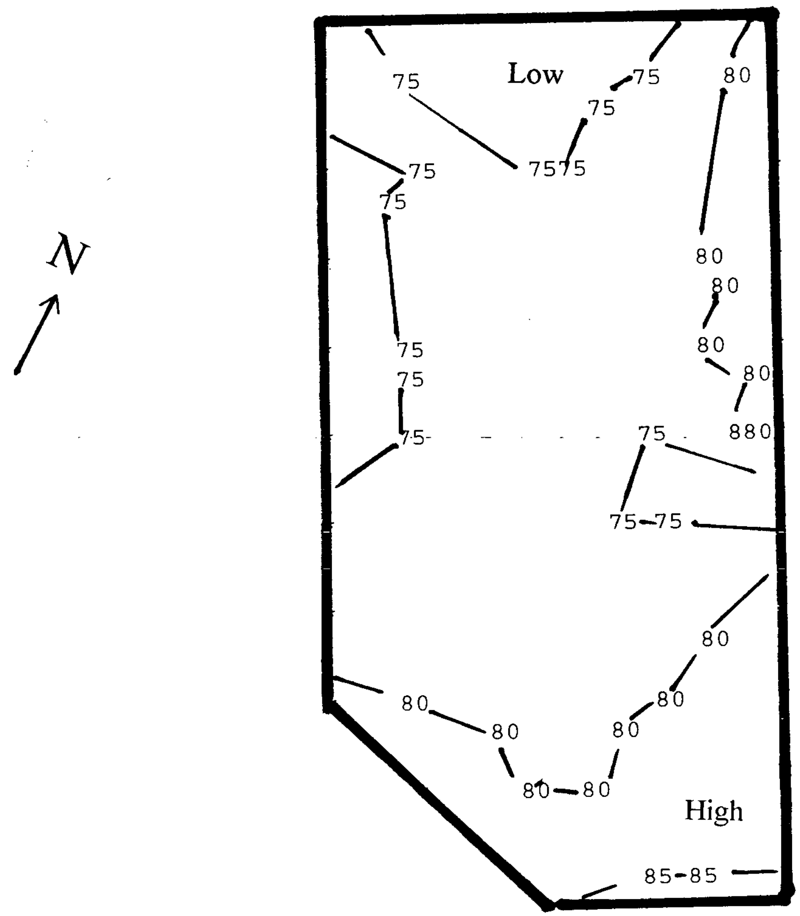
Field no: 2 Farm name: Herdmanston Field name: Stackyard



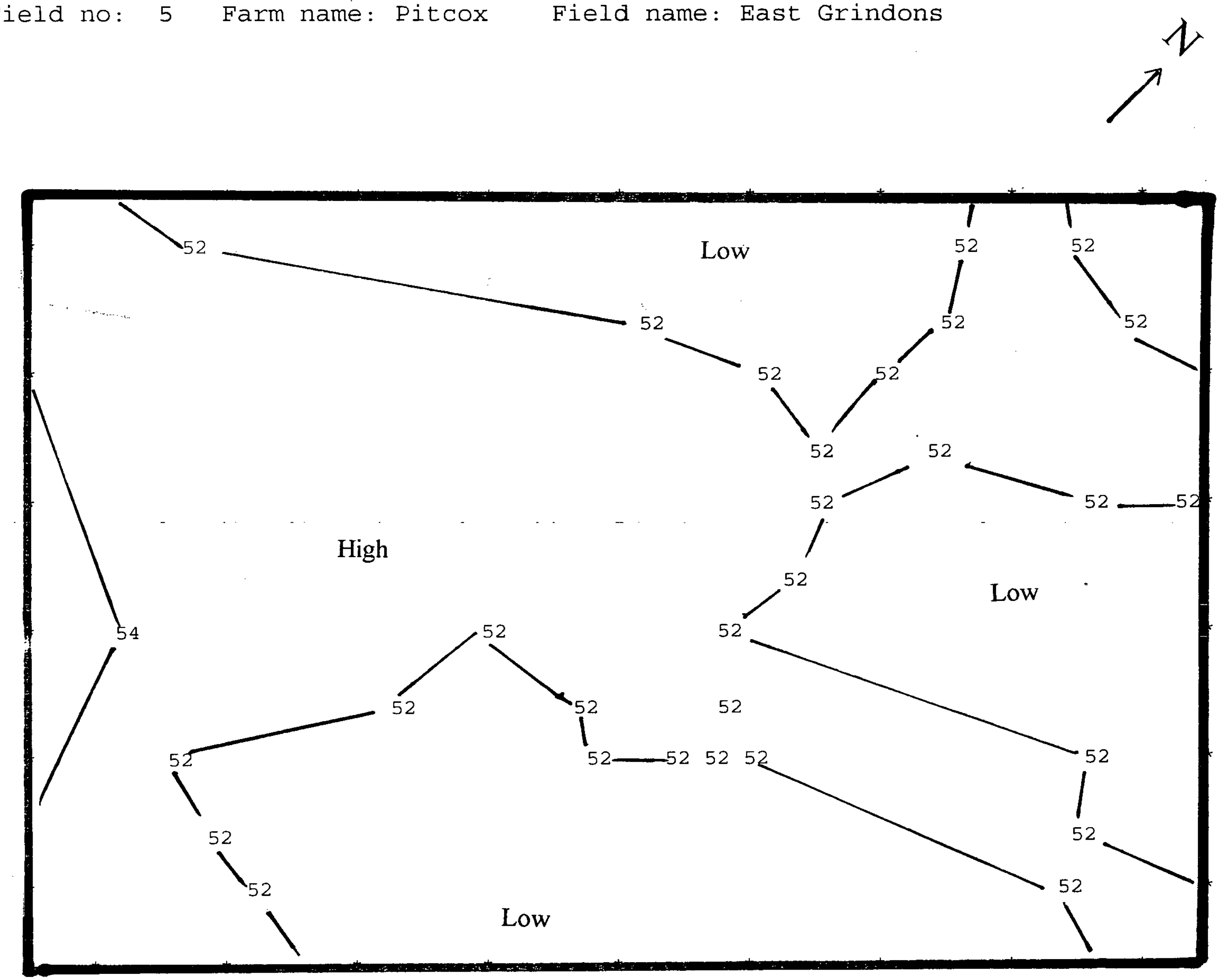
Field no: 3 Farm name: Luffness Mains Field name: Parks



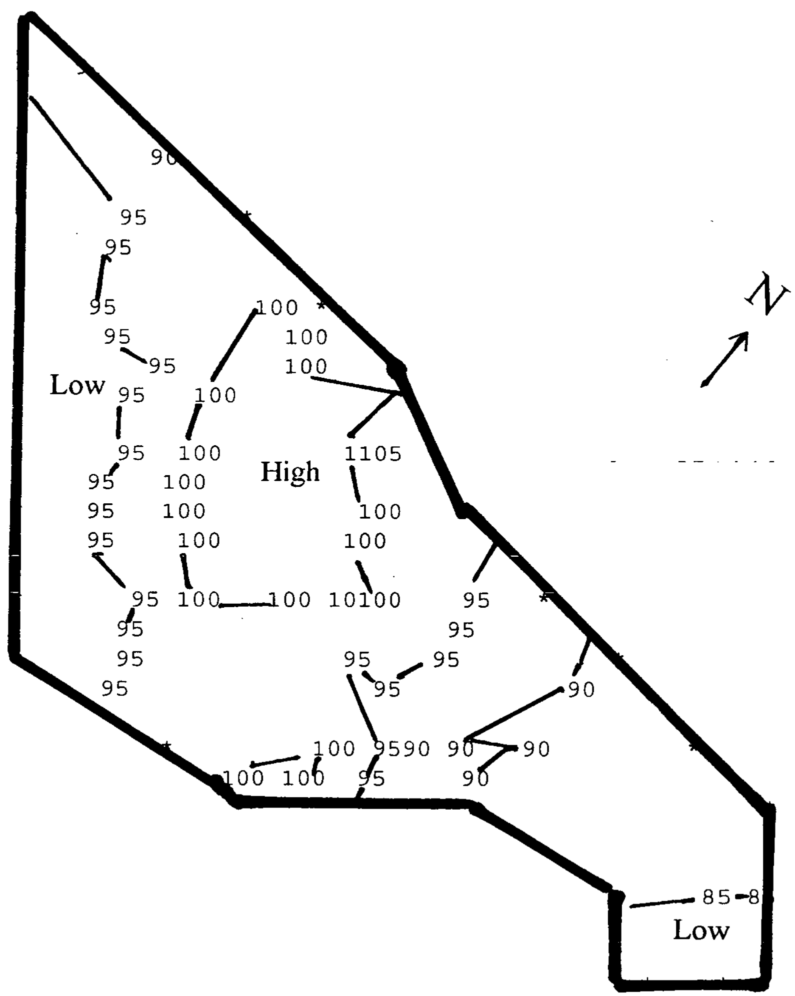
Field no: 4 Farm name: West Fenton Field name: Fisher's Neuk



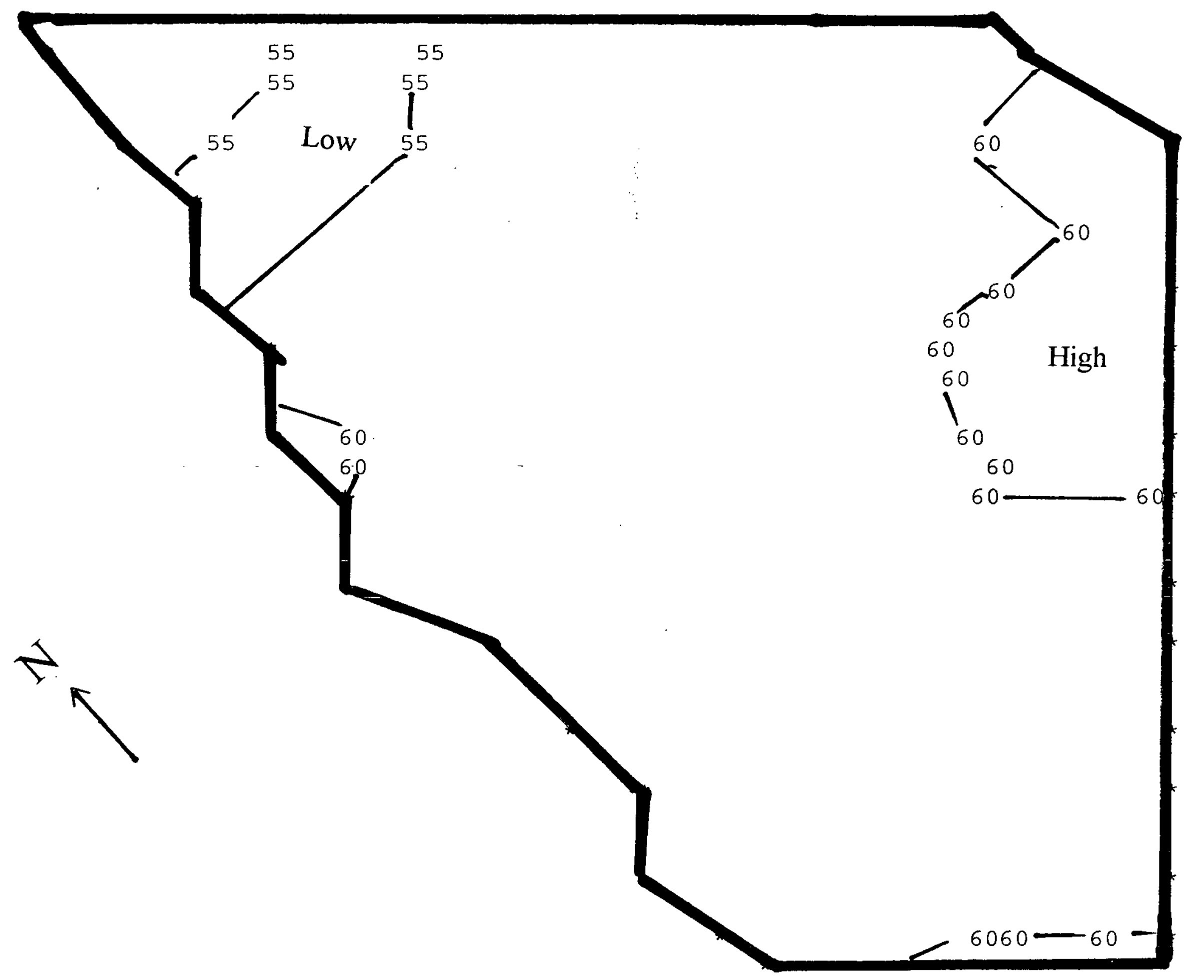
Field no: 5 Farm name: Pitcox Field name: East Grindons



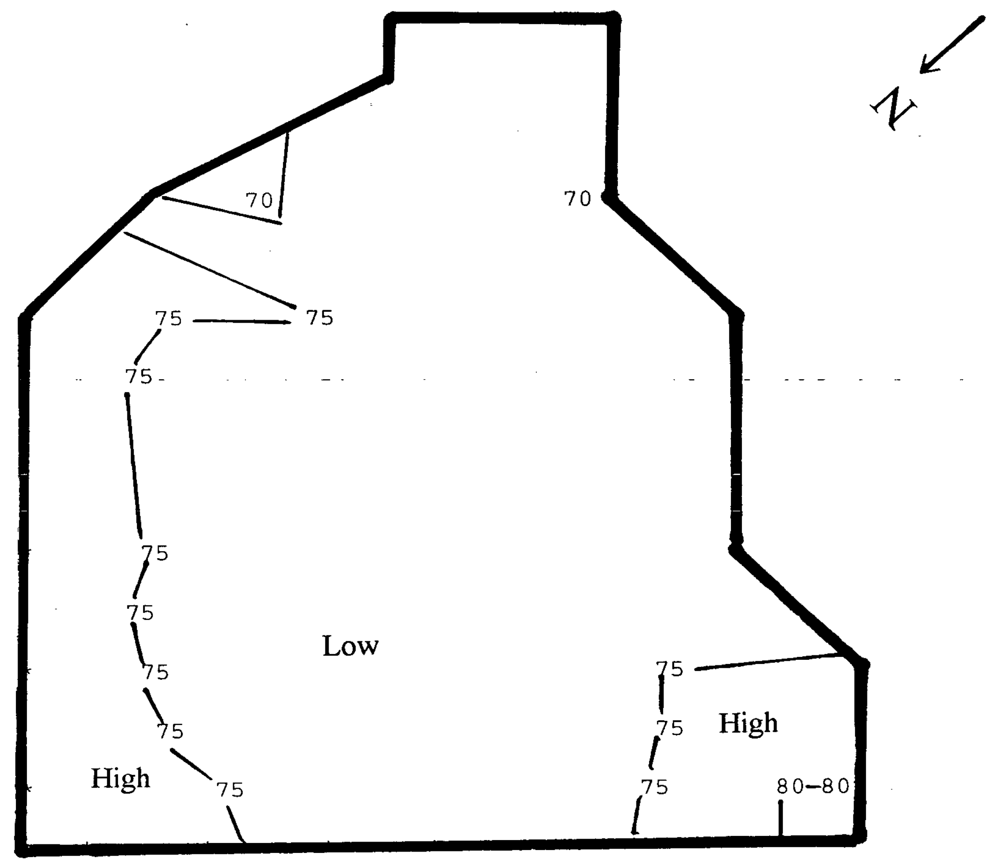
Field no: 6 Farm name: Remote Field name: Cottage



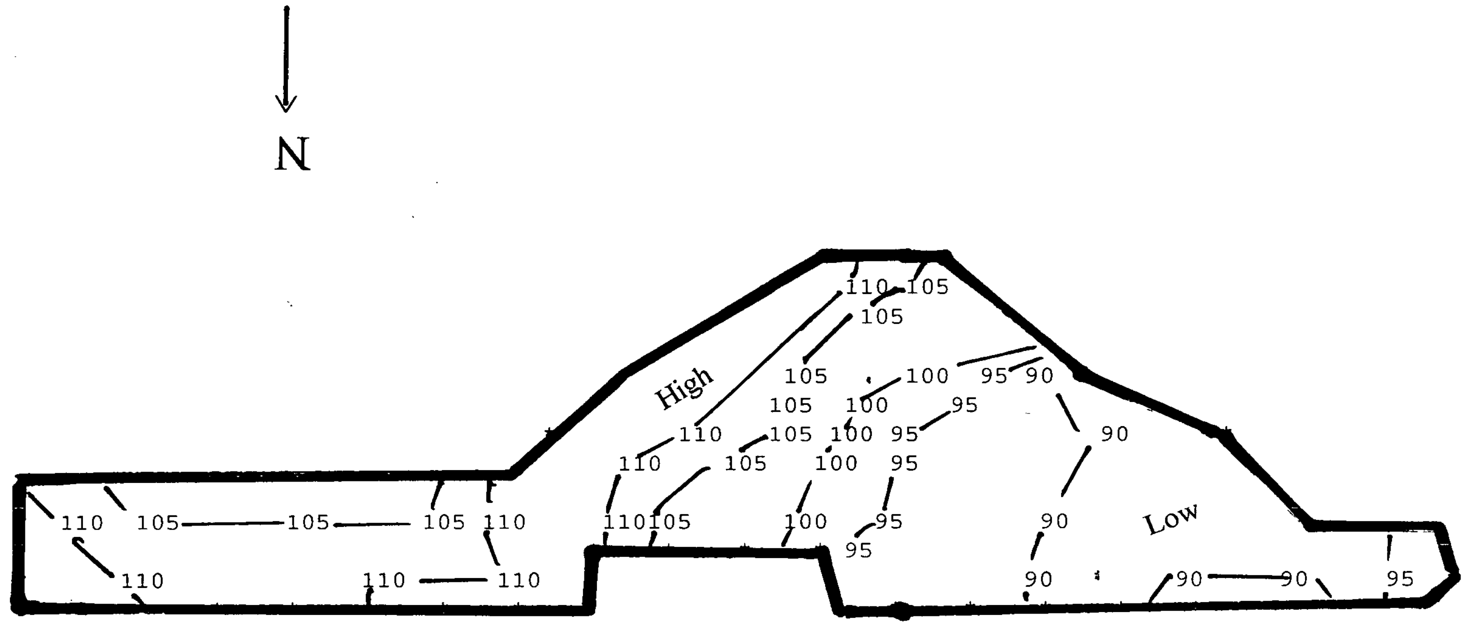
Field no: 7 Farm name: Dodridge Field name: 33 acres



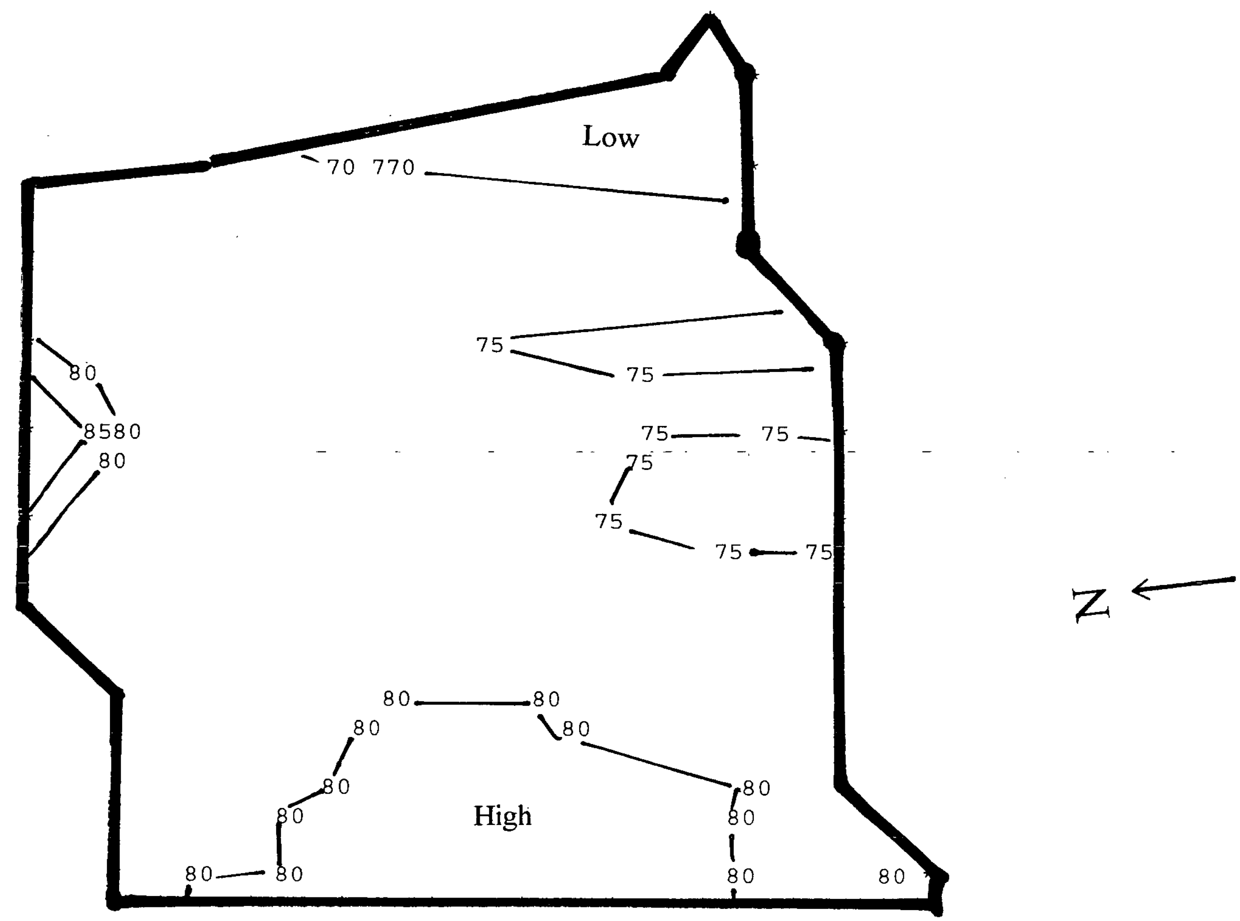
Field no: 8 Farm name: West Edge Field name: Kilns



Field no: 9 Farm name: Niddry Mains Field name: The Siding



Field no: 10 Farm name: Turniedykes Field name: Richardson's Rig IFS



Appendix 2

Measured values of potentially available nitrogen laid out in their relative positions in the field

Measured values of potentially available nitrogen in field 1

Farm name: Mortonhall Field name: Mid-Park

		100	79	88	61	81	
99	92	110	92	82	93	106	
117	96	90	98	98	98	106	
139	95	97	96	101	95	98	
123	115	103	111	104	108	107	95

Smoothed values of potentially available nitrogen in field 2
Farm name: Herdmanston Field name: Stackyard

65	64							
64	64	63	61	62	65			
64	62	62	61	61	63	65	66	
61	61	60	61	60	62	63	65	69
62	61	60	59	59	61	62	63	67
61	61	59	58	59	60	61	64	66
61	60	59	58	58	59	60	64	68
59	60	59	57	57	58	60	63	
61	60	60	58	57	58	59		
62	63	61	59	60	58	61		
62	61	60	60	63				
	64	62	60					

Smoothed values of potentially available nitrogen in field 3
Farm name: Luffness Mains Field name: Parks

63	63	64	64	63				
62	61	62	62	61	60	59	61	
62	61	61	62	60	59	57	59	58
62	62	62	62	60	59	58	59	59
63	63	62	62	60	59	57	58	60
64	65	64	62	59	60	60	59	60
65	64	64	63	61	59	59	60	62

Smoothed values of potentially available nitrogen in field 4
Farm name: West Fenton Field name: Fisher's Neuk

75	74	73	75	80
73	76	75	75	80
76	76	75	77	82
74	76	76	78	82
74	77	77	75	80
78	77	76	74	80
79	77	75 -	76 -	79
81	79	77	80	84
	84	78	83	84
		84	85	87

Smoothed values of potentially available nitrogen in field 5

Farm name: Pitcox Field name: East Grindons

53	51	50	51	51	50	50	53	51
54	54	53		54	52	52	53	52
53	54	54	54	54	52	52	52	52
54	53	53	52	53	52	52	52	50
52	51	51	50	52	52	51	52	52
54	52	51	51	51	51	51	51	53

Smoothed values of potentially available nitrogen in field 6
Farm name: Remote Field name: Cottage

89									
88	88								
90	96	99							
92	98	98	101						
91	93	99	100	102					
95	95	103	103	105					
93	97	104	102	100	97				
92	95	102	100	100	97	93			
91	95	97	99	95	96	92	91		
		101	104	98	88	91	88	87	
						88	88	87	87
								87	84
								89	89

Smoothed values of potentially available nitrogen in field 7
Farm name: Dodridge Field name: 33 acre

57	56	56	54	53	57	56	56	57	58	58	58	59		
	55	55	55	55	57	56	57	56	57	59	59	60	60	59
		55	55	56	57	57	58	57	57	58	59	60	59	59
		57	56	57	56	58	58	57	58	59	60	60	61	62
			58	58	57	58	58	59	59	60	60	61	61	61
			64	58	58	58	58	57	58	59	60	60	60	60
				59	59	58	58	57	58	58	59	60	60	60
				57	58	58	57	57	57	58	58	59	59	60
						58	57	57	58	58	58	58	58	59
							56	57	59	59	58	58	58	59
								57	59	59	58	58	58	58
								58	59	60	59	59	58	59
									59	60	59	60	60	61

Smoothed values of potentially available nitrogen in field 8
Farm name: West Edge Field name: Kilns

			72	70		
	66	73	71	70		
79	75	75	72	73	72	
73	75	74	71		72	
75	75	72	73	74	72	
76	74	70	71	73	76	77
76	76	70	72	72	76	81

Smoothed values of potentially available nitrogen in field 9
Farm name: Niddry Mains Field name: The Siding

										115	108							
								108	107	103	101	98	89					
							113	113	108	101	95	91	91	90	90			
110	105	106	105	108	104	112	112	104	102	99	94	93	90	90	92	92		
107	111	113	112	110	107	111					88	88	90	90	90	88	93	97

Smoothed values of potentially available nitrogen in field 10
Farm name: Turniedykes Field name: Richardson's Rig

							68		
		70	70	69	69	69	68		
73	71	71	72	73	72	71	72		
76	76	75	75	75	74	74	74	74	
87	77	77	78	79	79	77	73	76	
80	77	76	77	76	77	74	72	73	
80	77	76	77	79	79	78	77	76	
	77	77	79	82	80	77	78	78	
	76	80	80	82	82	81	82	79	
	81	79	83	82	81	82	81	78	80

Appendix 3

Smoothed values of potentially available nitrogen laid out in their relative positions in the field.

Smoothed values of potentially available nitrogen in field 1
Farm name: Mortonhall Field name: Mid-Park

		97	91	91	85	90	
101	98	100	95	92	94	97	
107	100	98	98	97	97	99	
113	102	100	99	99	98	99	
112	107	103	103	101	102	101	98

Measured values of potentially available nitrogen in field 2

Farm name: Herdmanston Field name: Stackyard

71	67							
67	70	64	58	61	75			
69	62	62	60	58	62	72	72	
57	59	58	65	57	67	61	68	83
68	60	61	52	56	61	59	60	73
61	63	52	55	54	60	57	71	69
63	62	61	56	52	56	52	68	85
52	58	58	51	53	54	58	67	
64	59	60	50	48	56	57		
62	74	66	56	62	52	65		
64	59	56	57	77				
	72	64	57					

Measured values of potentially available nitrogen in field 3
Farm name: Luffness Mains Field name: Parks

65	63	72	69	68				
64	56	65	60	59	60	58	66	
61	57	58	65	59	59	44	59	56
62	61	61	66	57	58	56	61	57
61	66	61	63	59	56	48	52	63
67	71	70	65	52	63	67	59	59
70	63	67	69	61	54	56	58	70

Measured values of potentially available nitrogen in field 4

Farm name: West Fenton Field name: Fisher's Neuk

78	69	67	70	88
62	83	72	68	85
79	79	71	75	92
66	78	72	83	93
63	80	79	62	87
81	78	75	61	87
82	74	66	67	79
85	79	72	80	98
	99	66	89	89
		91	91	95

Measured values of potentially available nitrogen in field 5

Farm name: Pitcox Field name: East Grindons

55	47	43	48	47	46	43	58	47
56	57	57		60	52	53	58	54
49	57	57	58	59	53	49	51	54
61	54	58	49	55	50	53	52	44
49	47	49	41	56	55	45	52	55
59	53	48	53	48	47	50	50	58

Measured values of potentially available nitrogen in field 6
Farm name: Remote Field name: Cottage

87									
80	71								
81	101	108							
87	111	98	108						
79	78	102	94	106					
97	84	123	108	128					
83	98	123	106	100	93				
84	83	122	100	112	98	87			
80	93	87	98	81	104	89	93		
		109	130	108	60	94	82	79	
						80	84	83	87
								86	71
								90	93

Measured values of potentially available nitrogen in field 7
Farm name: Dodridge Field name: 33 acre

59	58	59	47	43	61	54	54	56	61	60	54	59		
	52	51	53	48	60	51	59	48	51	64	57	66	62	57
		51	53	57	57	57	61	56	55	58	57	61	56	57
		59	50	58	51	60	60	47	56	60	61	60	62	69
			56	61	53	60	56	71	65	64	60	69	67	65
			92	52	58	61	57	52	55	63	60	62	60	61
				63	67	55	60	55	57	57	63	64	61	61
				52	56	59	53	51	55	55	55	60	61	63
						62	59	55	56	60	60	55	55	58
							46	50	64	62	52	57	56	61
								54	66	60	56	56	56	57
								56	58	64	60	61	51	61
									58	63	55	67	61	68

Measured values of potentially available nitrogen in field 8
Farm name: West Edge Field name: Kilns

			73	67		
	43	77	69	63		
96	78	85	69	77	72	
65	77	78	63		68	
77	82	68	75	78	67	
80	76	60	65	74	80	82
80	85	60	71	66	80	93

Measured values of potentially available nitrogen in field 9
Farm name: Niddry Mains Field name: The Siding

										146	121							
								106	108	98	102	107	71					
							127	133	123	102	85	74	88	85	86			
117	95	99	95	109	90	123	122	91	95	100	94	97	85	89	97	95		
104	117	126	122	116	105	118					69	73	88	88	87	77	94	102

Measured values of potentially available nitrogen in field 10
Farm name: Turniedykes Field name: Richardson's Rig

							62		
		64	63	57	59	63	55		
69	61	62	65	75	69	67	71		
68	76	78	77	77	69	72	76	75	
131	70	80	84	93	94	89	61	87	
80	72	73	80	65	76	61	54	66	
86	74	71	69	86	87	82	83	74	
	76	73	80	95	84	67	76	79	
	66	85	79	88	91	83	95	77	
	88	74	97	83	81	89	85	71	85