ABSTRACT.

This thesis is concerned with identifying the major sources of variation which influence the yield of potato varieties. The sources of variation can be considered to be of two types, (i) controllable variation, which can be reduced by use of a sound field plot technique, and (ii) uncontrollable variation, which arises from such influences as the weather.

The effect of the first type of variation was investigated in the literature and through field work. Some aspects of field plot technique were examined in small field experiments and the results of eight SPBS/PBI regional maincrop potato trials, which were planted in generalised lattice designs are presented and the effect on the trial precision compared to the standard trial design.

The effect of uncontrollable variation on potato trial yields was examined by analysis of a large quantity of NIAB maincrop potato yields, from trials grown in England during 1969-1978. The variate considered throughout is total yield of tubers at harvest.

The components of variance arising from the NIAB data were calculated and compared to variance components estimated from other agricultural crops. Two standard measures of the precision attainable by a trial system are given and the effect of the distribution of trials over years and centres on the precision is shown.

EX BIBL UNIV EDINBURGEN

The yield sensitivity parameter to differences between environments was calculated each year for the varieties tested and also the variety's yield sensitivity parameter to differences between years; the contrasting values estimated for these parameters for the same variety are considered. The analysis used to estimate these yield sensitivity parameters is shown to be equivalent to a multivariate method. The present model used to measure variety yield sensitivity is found to account for most of the variety variation.

An additive model and a graphical technique were applied to regional data from potato trials in England and Scotland to examine the variation in the regions of both countries. Correlations between the variety yields obtained in trials in English and Scottish regions were calculated in order to determine if different regions produced similar variety yield rankings. Correlations between variety yields at English sites were calculated each year to determine whether or not any sites are consistently well correlated.

Use of estimated environment effects enabled certain English sites to be identified that produce a wide range of environment effects; a wide range of environments is required to obtain a useful estimate of variety yield sensitivity to different environments.

The variability of varieties of potatoes,

by

William J. Fielding.

Submitted for the Degree of Master of Philosophy at

the University of Edinburgh, 1981.

Declaration.

I hereby declare that the work contained in this thesis has been composed by myself.

Acknowledgements.

I would like to thank Dr H.D. Patterson
and Dr R.J. Killick for their advice and guidance,
the NIAB for making their data available
and the SPBS for the facilities which made
the practical work possible.

This work was sponsored by the Potato Marketing Board.

List of abbreviations commonly occuring in the text.

(For abbreviations used in the Tables and Graphs see Tables 9 and 61.)

RMS	Residual Mean square
RSS	Residual sum of squares
GL	Generalised Lattice
RCB	Randomised complete block
SE	Standard error
CV	Coefficient of variation
V	total variety x environment variance
σ^2_{VC}	Variance of the variety x centre component
σ^2_{VY}	Variance of the variety x year component
σ^2_{VCY}	Variance of the variety x centre x year component
σ^2_{ϵ}	Plot error variance
RMS_{RCB}	Residual mean square from the RCB analysis
RMS_{GL}	Residual mean square from the GL analysis
β_i	Sensitivity of variety i of its yield to changes in its environment
I_j	Effect of environment j on the yield of the varieties
m	A general mean
v_i	Mean yield of variety i
y_{ij}	Yield of variety i at site j
EE	East of England Region
EC	East central region of England
ES	East of Scotland
NC	North Central region of England

NS	North of Scotland
SW	South West region of England
WC	West Central region of Scotland
WS	West Scotland
NIAB	National Institute of Agricultural Botany
SPBS	Scottish Plant Breeding Station, as from 1/2/81 part of SCRI, Scottish Crop Research Institute
PBI	Plant Breeding Institute
ADAS	Agricultural Developement Advisory Service
E	Efficiency of a generalised lattice design
E_*	Upper bound efficiency of a GL design
FITCON	Fitted constants
AUGFITCON	Augmented fitted constants
DHS/21	DHS64207/21

CONTENTS

	Page
INTRODUCTION.	1
CHAPTER 1 Effect of agronomy and husbandry on the yield rankings of potato varieties.	5
1.1 Introduction.	5
1.2 Factors which affect yield	5
1.3 A husbandry effect investigated.	6
1.4 Effect of centre on saleable yield.	6
1.5 Effect of husbandry practices on field trials	7
1.6 Discussion.	8
CHAPTER 2 Field plot technique.	11
2.1 Introduction.	11
2.2 Competition between potato plants.	11
2.3 Use of guard rows.	12
2.4 Influence of weather on guard rows.	13
2.5 Effect of guard rows.	13
2.6 Disadvantages of guard rows.	14
2.7 Plot shape, size and replication.	14
2.8 Plot shape.	15
2.9 Advantages of long narrow plots.	15
2.10 Plot size.	15
2.11 Replication number.	16
2.12 Use of long narrow plots.	16
2.13 Practical considerations of plot size.	17
2.14 Plot size and guard rows.	17
2.15 Block shape.	18

Page

2.16 Discussion. 19

CHAPTER 3 Experimental design. 20

3.1 Introduction. 20

3.2 Soil heterogeneity. 20

3.3 Plant variation. 21

3.4 Statistical design. 21

3.5 Incomplete block designs. 22

CHAPTER 4 Data collected. 27

4.1 Introduction. 27

4.2 Data analysed. 28

4.3 Variate analysed. 29

CHAPTER 5 Genotype x environment interaction. 30

5.1 Introduction. 30

5.2 Method. 32

5.3 Analysis. 32

5.4 Partitions of the data. 33

5.5 Interpretation of variance components. 34

5.6 Effect of drought years. 35

5.7 The contribution of the variance components to the total variety x environment interaction variance. 36

5.8 Critical differences. 37

5.9 Estimated critical differences. 38

5.10 Discussion. 38

5.11 Acceptance probabilities. 39

5.12 Results. 40

5.13 Discussion. 40

5.14 Comparison of ratios of estimated variance components. 42

Page

5.15 Results. 42

5.16 Discussion. 43

CHAPTER 6 Analysis of residuals. 44

6.1 Introduction. 44

6.2 Method. 44

6.3 Results. 46

6.4 Residuals as indicators of variety adapability. 46

6.5 Discussion. 47

6.6 Fitted Constants. 48

6.7 Results - Variety x environment adaptability. 49

6.8 Results - Variety x region adaptability. 50

6.9 Discussion. 51

CHAPTER 7 Estimation of variety sensitivities. 52

7.1 Introduction. 52

7.2 Interpretation of variety sensitivities. 52

7.3 Regression model. 53

7.4 Modified regression analysis. 53

7.5 Estimation of β_i, the yield sensitivity parameter. 54

7.6 Estimated β_i. 54

7.7 Influences upon estimated values of β_i. 55

7.8 Analysis of year, variety and centre upon $\hat{\beta}_i$. 56

7.9 Results. 57

7.10 Sensitivity of variety yield to differences between years. 58

7.11 Results. 58

7.12 Discussion. 59

7.13 Comparison of β_i estimated from agricultural and trial data. 61

Page

CHAPTER 8 Regression analysis and singular value decomposition. 63

8.1 Properties of SVD. 63

8.2 Relationship between the regression model and the spectral decomposition of the variety x centre table. 63

8.3 Link between AUGFITCON and SVD. 66

8.4 Use of the SVD when the data are incomplete. 68

8.5 Application of SVD to a completed variety x environment table of yields. 68

8.6 Extension of AUGFITCON. 69

8.7 Link between model (3) and the SVD. 70

8.8 Calculation of the regression model (3). 72

8.9 Incomplete data. 73

8.10 Number of interaction terms required in model (3) - complete tables. 74

8.11 Error in $\hat{\lambda}_i$ in complete data tables. 74

8.12 Number of interaction terms required - incomplete tables. 75

8.13 To test the hypothesis that p-k latent roots of the data matrix are equal. 76

CHAPTER 9 Use of the Biplot. 78

9.1 Introduction. 78

9.2 Method. 79

9.3 Results. 79

9.4 Discussion. 80

9.5 Application of Biplot to examine national effects. 80

9.6 Results. 80

9.7 Discussion. 81

Page

CHAPTER 10 Mean variety yields as percentages. 83

10.1 Introduction. 83

10.2 Method. 83

10.3 Results. 83

10.4 Discussion - Table 42 84

10.5 Use of agggregated data. 85

10.6 Results. 85

10.7 Discussion - Table 43 86

10.8 Variety x year data. 88

10.9 Results. 88

10.10 Discussion. 89

CHAPTER 11 Analysis of mean yields by an additive model. 90

11.1 Introduction. 90

11.2 Variety x year data. 90

11.3 Results. 90

11.4 Discussion. 91

11.5 Variety x region data. 91

11.6 Discussion. 92

CHAPTER 12 A comparison between English and Scottish regional trial results. 94

12.1 Introduction. 94

12.2 Method. 94

12.3 Results. 95

12.4 Discussion. 96

Page

CHAPTER 13 Correlations between environments and between varieties. 98

13.1 Introduction. 98

13.2 Effect of missing values on the correlation coefficient. 99

13.3 Effect of estimated values in the corrrelation matrix. 99

13.4 Example of the effect of AUGFITCON estimates on the correlation matrix. 101

13.5 Calculation of correlation coefficients. 102

13.6 Results. 102

13.7 Discussion. 104

13.8 Correlations from mean yields over years at different regions. 105

13.9 Correlations from yields at English and Scottish regions 106

13.10 Region x region correlations, England. 107

13.11 Region x region correlations, England and Scotland. 107

CHAPTER 14 Recommended varieties. 109

14.1 Introduction. 109

14.2 Importance of yield potential. 111

14.3 Variance components arising from recommended and non-recommended varieties. 111

14.4 Analysis. 112

14.5 Results. 112

14.6 Discussion. 112

CHAPTER 15 Variety pedigree. 113

15.1 Introduction. 113

15.2 Some variety relations. 113

15.3 Connections between related varieties. 114

Page

15.4 Summary. 116

CHAPTER 16 Environment effects. 117

16.1 Introduction. 117

16.2 Method. 117

16.3 Results. 119

16.4 Discussion. 121

CHAPTER 17 Analysis of the sites. 124

17.1 Introduction. 124

17.2 Method. 124

17.3 Results. 124

17.4 Discussion. 125

CHAPTER 18 Use of Generalised Lattice designs in potato variety trials. 127

18.1.1 1979 Experiments. 127

18.1.2 Site description. 127

18.1.3 Design description. 128

18.1.4 Design layout. 128

18.1.5 Trial harvest. 128

18.1.6.1 Results. 129

18.1.6.2 Comparison of randomised complete block and generalised lattice analyses. 129

18.1.6.3 Effect of eelworm on results. 130

18.2.1 1980 Experiments. 130

18.2.2 Site description. 130

18.2.3 Design description. 131

18.2.4 Design layout. 131

18.2.5 Results. 131

	Page
18.2.6 Comparison of Generalised Lattice and randomised complete block analyses.	132
18.3.1 Demonstration experiment 1979.	132
18.3.2 Design description.	133
18.3.3 Comparison between NIAB trials and the demonstration experiment.	133
18.3.4 Trial layout and harvest.	133
18.3.5 Results.	134
18.4.0 Results.	134
18.4.1 Efficiency of GL designs.	134
18.4.2 Observed advantage of GL designs.	135
18.4.3 Effect of GL analysis on a NIAB type trial.	136
18.4.4 Difficulties with GL designs.	136
CHAPTER 19 Conclusions.	138
APPENDIX Practical work not on generalised lattice designs.	144
P.1 Spacing experiment at The Murrays in 1978.	145
P.2 Experimental debris from 1978 split-plot experiment.	148
P.3 The Murrays experiment 1979.	150
P.4 The relationship between total yield and saleable yield as displayed in the 1978, 1979 experiments.	152
APPENDIX II NIAB trial instruction leaflet.	154
TABLES 1-61	158
GRAPHS 1-26	221
DIAGRAM L	246
TABLES 1A-5A	247
TABLES S1-S2	252
TABLE 1E	253

	Page
TABLES G1-G2	254
TABLES R1-R2	255
REFERENCES	256

INTRODUCTION.

Variability in yield is a common feature in all agricultural crops, whether the crop is a grain or root crop. However, the source of variation with the greatest effect on yield may not be the same for all crops.

Identification of the major causes of yield variation in agricultural crops is important since breeders can then screen their selections for adverse reactions and thus choose relatively consistent varieties.

Examination of the varieties' yielding ability to adapt to a range of environments can help identify varieties which have a specific or general adaptability to environments. This knowledge is useful in a breeding programme when a variety with a certain adaptability is desired.

Potatoes exhibit many differences to other major agricultural crops grown in this country inasmuch that they are botanically dissimilar, for instance to barley. Potatoes grow under the soil surface, cf cereal seed, so the depth of the root systems and the depth of cultivation are important factors affecting tuber yield. With a cereal crop the yield is of 'true' seed, whereas with potatoes the yield is of tubers, the gross weight of which may be considerably different to dry weight. The growing season for potatoes is later than for spring cereals and very different from winter cereals, (March - August for spring cereals and April -

August/September/October for potatoes.) Compared to cereals, potatoes have a much larger storage organ and the method of handing potato seed can influence the yield obtained from it. This storage organ can carry effects (e.g. diseases) over from one generation to another.

Differences such as those mentioned above have led breeders to consider the possibility that environmental factors may not affect potato yields in the same way as yields of other crops, e.g. cereals. The factors affecting yield include those that arise from variation due to the plant material, the way in which the plant is cultivated, where the crop is grown (centre effects) and when the crop is grown (year effects). The effects of disease, as well as the effects of centre and season will all be influenced by weather effects. This study has attempted to detect the factors which have an important effect on the total yield of potato varieties. Once these main factors have been ascertained the precision of the current national potato trial programme can be determined and the effect of modifications on the precision of the testing system calculated.

Potato trial data from National (English) trials, organised by NIAB (National Institute of Agricultural Botany), were used to investigate uncontrollable factors influencing yields. (The purpose of these NIAB trials, from which the data is taken, is to test varieties prior to their possible inclusion on the National/Recommended Lists of potatoes.) The variate considered was total yield of tubers. The regions where the trials were

performed vary considerably; the western sites are wetter than the eastern sites and could be expected to give different results. Identification of differences between groups of sites such as these could enable sites to be chosen to test particular characters, or it may be found that a certain subset of the sites gives little information not already available from other sites. If this were the case, i.e. the yields from sites are consistently highly correlated, then some of the sites could be omitted without losing much information as to how the varieties interact with the environment.

A smaller series of trials is performed in Scotland each year to test varieties under Scottish conditions. If differing results were obtained in these trials compared to those from English trials then the results from the two series of trials should be kept separate. These results would also suggest that not only should different varieties be recommended in the two countries, but that perhaps the Scottish regions have different affects on variety yields compared to the English regions. Dissimilar results would suggest that the trial systems should be continued in parallel.

Work done on cereals, by among others Patterson, Silvey, Talbot and Weatherup (1977), and soybeans, Schutz and Bernard (1967), show that the variance component due to year differences is the most important variance component affecting yield results in a trial scheme. Estimation of the components of variance from replicated field trials can enable the effects of years and centres on potato yields to be investigated. Comparison of the variance components

with other crops will indicate whether or not potatoes can be regarded as being affected differently by these variation sources compared to other crops.

Statistical techniques, applied to cereal crops, have been applied to English and Scottish potato trial data. The sensitivity parameters of the variety's yield to different environments have been calculated. If the effect of year differences on potato yields are large these sensitivities may not be very helpful in assessing the variety's sensitivity. The sensitivity parameter of the varieties' yield to differences between years may, if the effect of years on variety yield is important, be a more reliable indicator of the variety's yield sensitivity.

CHAPTER 1

Effect of agronomy and husbandry on the yield rankings of potato varieties.

1.1 Introduction

The way in which potatoes are grown can affect the yield attained at the end of the season. A general reference which covers this area in depth is 'The Potato Crop' (ed. Harris, 1978).

This section highlights some husbandry factors that can influence variety effects and which may alter the relative variety yields in a trial.

1.2 Factors which affect yields.

Table 1 lists some of the most common differences between growing regimes and whether these differences influence the ranking of the variety yields. In some cases there is no simple influence of a given factor upon the yield. Whether a given factor has a varietal effect may depend upon the weather conditions and how the seed was planted, e.g. Palmer and Jarvis (1976) found that delayed planting does not necessarily cause a reduction in yield if well sprouted seed is used, the reverse of Munro and Scourey (1976).

Allan and Scott (1980) have shown that by careful preparation of seed to maximise the radiation intercepted yields obtained by use of conventional husbandry can equal or better the yields obtained from

the 'blue print' method (Evans, 1975), but they have yet to demonstrate a varietal effect. There have been many claims about the effect of physiological age on the yield of potatoes, but no varietal effects have yet been demonstrated.

1.3 A husbandry effect investigated.

The experiment performed at The Murrays, the experimental farm of the SPBS (Scottish Plant Breeding Station) in East Lothian, in 1978 to investigate the presence of a spacing effect on varieties did not detect any interaction between variety and spacing. The experiment is described in appendix I. Wurr (1974) obtained contrary results; possibly the detection of variety x spacing interaction depends on the season.

1.4 Effect of the centre on saleable yield.

As well as many climatic effects which give each centre its particular character there are many sources of variation within a given site which affect saleable and total yield.

Sources of variation attributable to the sites include:

(i) The quality of the seed-bed. This will influence the uptake of nutrients and water during the whole season and therefore may affect the incidence of cracking and secondary growth.

(ii) The depth of planting. This influences the level at which tubers are formed which in turn affects incidences of greening.

(iii) The final ridge must be large enough to prevent greening

as far as possible. Sufficient tilth must be produced for the ridge but this must not lead to excessive drying. Excessive drying may increase the incidence of cracking, secondary growth and the production of badly shaped tubers.

(iv) Blight control must be effective. Tubers must be prevented from becoming infected and thus reduce the number of substandard tubers.

(v) Pest control must prevent attack by slugs, wireworm etc, (Harris, 1978).

Greening, cracking, secondary growth, susceptibility to mechanical damage, certain tuber diseases and pests are all factors which are affected by variety. It is varietal characteristics such as these that trials are designed to evaluate. However these characters may be manipulated through use of a particular husbandry for a given variety, i.e. the effect of some of the variety's attributes can be altered by a change in the husbandry. Thus the results from several trials should be examined to evaluate the overall performance of a variety.

1.5 Effect of husbandry practices on field trials.

Table 1 shows that there are many husbandry treatments that may influence the results obtained from any one trial. Each individual NIAB trial is performed to evaluate the performance of varieties under local conditions; for this reason the trials are performed according to 'local practice'. The instructions for performing NIAB trials, sent to all trial officers, appear in Appendix II.

From this instruction leaflet four points are noted that could affect the trial results obtained:

(i) 'Chit in the light in a frost free building. All varieties receive the same chitting treatment.'

(ii) 'Closely graded seed should be supplied.'

(iii) 'Plot size may be varied for local convenience... Typical plot sizes may be six rows by twenty five setts or four rows by thirty setts...'

(iv) 'Drill width, sett spacing, planting date, cultivations, manurial treatment etc. should be in accordance with local practices.'

The final yield recorded is the result of a complex interaction of many factors affecting the variety and its environment. If the husbandries used are very dissimilar the trials at different sites may not be strictly comparable; the results recorded will be a complex mixture of variety x environment and variety x husbandry interactions. However, it is unlikely that farming practices differ sufficiently within England to make the variety x husbandry interaction important compared to the variety x environment interaction. Growing trials under local husbandry enables the varieties to be tested under the growing conditions relevant, and suitable, to that locality.

1.6 Discussion.

The aim of a single variety trial is to test varieties in a particular set of conditions. The aim of a set of breeders' trials

is to test over a range of different conditions. NIAB and other national testing bodies aim to test varieties over a representative or random sample of growing conditions. The aim of variety trials is to test varieties over a wide range of growing conditions. The husbandry practices at each site may differ, yet each corresponds to a permissible regime - regimes evolved through experience of potato growing to produce good results at each site. Hence the husbandry factors may be regarded as part of the 'natural' environment. Only when the husbandry effects within a trial are such as to modify the yields beyond that due to the natural environment (e.g. use of different seed sizes for different varieties) must steps be taken to alter the way the trial is performed.

The main drawback with trials performed 'according to local practice' is that the husbandry used will be such as to obtain high yields from the currently listed varieties, or control varieties of which the farm manager has experience. Unless a test variety has similar optimal cultivation conditions as the standard varieties the variety may not reach its potential yield and so could be dropped. This circumstance makes it desirable that as many promising varieties as possible should be sent to the Agricultural Development Advisory Service, ADAS, for testing so as to enable the full potential of the variety to be realised under its optimal growing conditions. (ADAS perform tests to find the optimal cultivation conditions for some varieties on the National List.)

Although the environment may be considered to consist of two types of variation: uncontrollable effects (e.g. weather) and

controllable effects (e.g. husbandry), the weather effects influence almost all aspects of husbandry including the levels at which treatments, e.g. fertilizers, become optimal (Jarvis and Schotten, 1967).

Weather effects, which are clearly unalterable in the field, dictate when trials may be planted and harvested. These two dates have important results on potato yields (Toosey, 1964). The date of harvest may alter the final yield rank order (Medac and Perrenec, 1955). If the husbandry were to be fixed for all trials the levels chosen will be of utmost importance. Lack of knowledge of the response of new varieties to husbandry treatments and practical necessity force some treatments to be fixed for all varieties within a trial, (e.g. spacing, fertilizer levels). Some treatments could be different for each variety; for instance on entering a variety for trial the breeder could recommend storage conditions.

However practical conditions constrain the husbandry to certain limits and introduce a 'practical bias' into the results, in favour of those varieties that perform 'well' under commercial conditions. If these constraints only allow a fairly narrow band of husbandry treatments, then the use of varied husbandries in a comparative set of trials may introduce slight variation compared to other sources of variation.

CHAPTER 2

Field Plot Technique.

2.1 Introduction

Use of a good field plot technique is important if precise results are to be obtained from field trials. Field plot technique comprises all those aspects of trials which may affect the precision of the results. The effect that cultivation can have on trial results has been considered in chapter 1, and is omitted here. The factors discussed in this chapter include the numbers of replication, plot shape and size necessary to gain precise results. Less work has been done on potato field plot technique compared to other crops (Jacobs, 1953), even though this topic is central to precise trials.

2.2 Competition between potato plants.

Competition effects can be important in small plots, whether or not different varieties are grown adjacently. Chittenden (1919) showed that the position a plant occupied in a plot without guard rows influenced its yield. He found that corner plants gave the highest yield and that the yield decreased from the outer rows through to the innermost rows which yielded least. When different spacings were employed between plants Wilson and Chittenden (1919) found that the greater the space for an individual plant the greater its yield. These results agree with experiments using more modern methods performed in 1978 and 1979 at The Murrays. (See

Appendix I.)

The results of the 1919, 1978 and 1979 experiments have not always been reported. Brown (1922) found no effect of competition between adjacent plants although Ary and Hayes (1918) and Ary (1921), Myers and Perry (1923), Kalanker (1932) and Justensen (1932) noted the reverse effect; the latter suggested the use of guard rows so that varieties would be given their 'true' rank.

2.3 Use of guard rows.

Myers et al (1923) and Musgrave (1924) observed that the use of one discard row was sufficient to prevent edge effects giving 'erroneous' results in the plot values recorded. This result is important if a 'ripple effect' occurs in the potato plot. (A 'ripple effect' is said to occur when the yield in alternate rows across a plot are higher and then lower than the plot average.) The ripple effect is caused by competition between adjacent rows; Hornsey (1979) has demonstrated this effect in sugar beet plots. The effect in a small plot could increase the variation and so decrease the precision of the trial. Examination of the trials at The Murrays in 1978 and 1979 when the border rows were excluded from the analysis gave a lesser residual mean square (RMS) than when the trials were analysed with the guard rows included.

2.4 Influence of weather on guard rows.

Steward (1927) suggested that competition effects have not always been found between plants since competition effects are more important in wet years than in dry years; thus the effect of guard rows may depend upon the season.

2.5 Effect of guard rows.

If guard rows have a seasonal effect they should be included in trial designs, since the climate in the season cannot be predicted at planting. Results from The Murrays, in 1978 and 1979, indicate that the rank order of the varieties is almost unaltered, irrespective of the guard row harvest and that more precise results are obtained when the experiments were analysed without the produce of the guard rows. Skinner and Hogarth (1980), for sugar cane experiments with three row plots recommended that all three rows should be used, whereas for four row plots they recommend use of the two centre rows. Kalamkar (1932) found that the standard deviation of a single plot was higher when guard rows were discarded than when the yield of the entire plot was used. These conflicting results concur with the hypothesis that the effect of guard rows are seasonal.

2.6 Disadvantage of guard rows.

A large amount of plant material is lost by use of discard rows. Long narrow plots may result in up to two thirds of the planted material being discarded. Even use of an almost 'square' plot causes one fifth of the total material to be discarded. Table 2 shows the percentage of the total material that is lost when guard rows are used; in each layout the same number of plants per plot are planted, and guard rows are assumed to consist of only the outermost side rows. These plans show that under such circumstances less material is used in guard rows if the plot is close to a square shape.

2.7 Plot shape, size and replication.

All researchers who have examined plot shape and size in variety trials agree that there are upper limits to plot size and lower limits on the number of replications after which reduction in experimental error is so small as to be of little practical value.

The experiments performed by the research workers have varied considerably and reference should be made to the original papers to obtain full details. The object of these experiments has been to determine the plot shape and size that produces the lowest standard error or coefficient of variation (CV) per plot.

2.8 Plot shape.

In general long narrow potato plots exhibit less variability than square or short wide plots, Table 3. Long narrow plots are only less variable if the length of the plot lies along 'the direction of greatest variation'; if this condition is not met then square plots are preferable (Day, 1920). Day's second assertion seems more reasonable than his first.

2.9 Advantage of long narrow plots.

Krantz (1936), who found that the CV decreased as the plot width was increased, suggested that most soils vary in productivity in circular areas and that the wider plots would tend to coincide with these fertility rings, whereas the larger plots cut across them. (Krantz had his plots at right-angles to the highest fertility gradient.) Justensen (1932) explained the superiority of long narrow plots over squarer plots by suggesting that this is due to 'slicing up' of the local differences when long plots are used, so that the differences are more evenly distributed over plots than when the plots are wider.

2.10 Plot size.

As plot size is increased two opposing factors affect the plot variation; firstly there is a tendency to average out plant heterogeneity with a consequent reduction in error, and secondly

there is an increase in the range of soil variation within the plot. The former effect predominates in small plots and the latter in larger plots. Some proposed plot sizes are given in Table 3; there is little agreement between suggested sizes but the length that appears most often is 12.2m with a range from 2.2m to 30.2m. The early workers considered single row plots but Thompson (1934) suggested the plots should be made up of adjacent rows.

2.11 Replication number.

Most authors recommend the use of small plots replicated many times. Krantz (1936) showed that smaller plots are always more efficient over a given area because replication is more effective in decreasing variation than increasing the plot size. Nonneck and Smillie (1964) and Killick (1980) found that the amount of replication required depends on the size of the plots and the desired accuracy. Kempthorne (1952) gives the theoretical justification for the use of many replications of small plots. The number of replications most commonly suggested is four or five; this recommendation is consistent even though the actual plot size varies considerably.

2.12 Use of long narrow plots.

All the standard farm implements are designed for use on long rows. Cultivations performed in the field by machine are more easily carried out on a rectangular block, so rectangular blocks have an important practical recommendation. The disadvantage of

using long plots (especially if narrow plots are used with guard rows) has already been demonstrated. So although there may be an optimal plot shape and size, in terms of trial precision and land usage, practical considerations may force the design away from what is desirable (Lana et al, 1953).

2.13 Practical considerations of plot size.

Although land economy decreases as plot size increases, Kalamkar (1932), plot size may have to be larger than the optimal since there may be insufficient labour to tend the plots. More recording and scoring is necessary at harvest if many small plots are used compared with fewer larger plots. For these reasons the recommendations in Table 3 can only act as a guide to trial design; what is possible in an individual experiment will depend on the resources available.

2.14 Plot size and guard rows.

NIAB potato trial plots are four or six rows wide and 30 or 25 setts long, the outer rows are guard rows and omitted in the yield analysis. Hence the plots are rectangular and up to 50% of the planted material may be discarded.

The plot size thus falls between the recommended sizes in Table 3. Each trial consists of four blocks, which is the miminum number of replications recommended in Table 3.

Analysis of the NIAB trial data shows that the average coefficient of variation, CV, = 8.4%; a trial with a CV under 10% is regarded as reasonable. SPBS/PBI trials use a smaller plot size, four rows of six setts and all rows of the plot are harvested for the yield analysis. In the eight SPBS/PBI trials analysed the residual mean square values, from randomised complete block analyses, were considerably lower than the NIAB values. Although there are many differences between the environments of the two sets of trials the fact that the SPBS/PBI residual mean squares are not larger than NIAB values suggests that use of a smaller plot size and inclusion of the border row produce need not compromise precision, Table 3A.

2.15 Block shape.

Much less work has been done on block shape compared to plot shape. Fisher (1966) recommends the use of square blocks saying, 'a safe rule is to make the blocks as compact as possible.' Nonneck and Smillie (1964) suggest the use of long narrow blocks in potato trials to reduce variation but Killick (1980) suggests that block shape has little effect on the variation. As well as possibly affecting the precision attainable by the trial, the block shape may influence the effect of natural factors on the foliage and other parts of the potato plant. For example, wind damage is likely to be greater if the plants occur in a narrow block than in a compact block.

2.16 Discussion.

The data upon which this study is based comes from trials planted in randomised complete block designs, see 2.14 above. The blocks are frequently two plots wide and n/2 plots deep, thus the blocks are usually long and narrow. Each trial is usually made up of four replications; the modal number of varieties in the trials is eight, so in many cases the block size is not large. The number of varieties in the trials varies, from 4 to 24, so the block size in the trials can vary considerably. As the block size is increased it is reasonable to expect the error variance to increase and so result in less precise trials than when the blocks are small. Reference to Table 4 indicates that although this hypothesis is not necessarily so, there is a wide range in the RMS for a given block size. The most recent trials have tested a larger number of varieties in each trial than in the earlier trials. The larger block size can be expected to increase the chance of a high RMS and so any revision of the current experimental design which produces a design that is likely to increase the precision of a trial and which is easy to use would be worthwhile. Use of an incomplete block design is described in chapter 3.

CHAPTER 3

Experimental design.

3.1 Introduction

We have seen in chapter 1 that there are many uncontrollable sources of variation which may affect the trial results. One way in which the precision of the trial may be increased is by using an efficient experimental design. The design must aim to minimise the unexplained variation in the experiment.

3.2 Soil heterogeneity.

The soil in a given area will often be far from uniform and a fertility gradient will probably cross the experimental site. Because of these effects experimental sites should be chosen with great care to ensure that the soil is as homogeneous as possible, so as to reduce the unexplained variation or experimental error. Harris (1920a) and Harris (1920b) gave examples of sites which were selected for their apparent uniformity but which, practically without exception, showed unexpected variability. Harris and Scofield (1928) showed that in even small experimental areas there exists a positive correlation between yields from the same plot in consecutive years.

3.3 Plant variation.

There is considerable between-plant yield variation. This is an inherent source of variation arising from the potato plant (Steward, 1927). A large plot size will reduce this source of variation but increase the soil heterogeneity within a plot.

3.4 Statistical designs.

A suitable statistical design coupled with a good field plot technique will help minimise the variation mentioned in 3.2 and 3.3 above.

The trial area is usually divided into blocks, with each variety appearing in each block. The most commonly used design of this type is the randomised complete block design (RCB). Thus soil heterogeneity is partially countered by grouping adjacent plots into blocks and assigning the varieties at random to plots within each block and by having enough plants in a plot to keep the between plant variation as low as possible.

If the number of varieties in a trial is large the blocks of a randomised complete block (RCB) design become large (unless very small plots are used) with the result that within-block variation will increase. Thus a design that uses many blocks, yet does not require a very large area of land, should be advantageous. For this reason incomplete block designs may be preferable to randomised

complete block designs.

3.5 Incomplete block designs.

One way of reducing the size of experiments is to use incomplete block designs. These are designs where each variety does not appear in every block. The varieties are allocated to blocks so that contrasts between blocks are aliases of least interesting comparisons or high-order interactions (Finney, 1960). In variety trials the experimenter would aim to arrange the varieties so that contrasts between varieties are confounded as equally as possible.

Until recently incomplete designs were of two main types, (i) balanced and (ii) partially balanced designs.

Balanced designs are incomplete block designs where each variety occurs r times and each pair of varieties occur in λ of the b blocks. These conditions ensure that all contrasts between varieties are equally precise. However, these requirements restrict the use of these designs, since although a design can be found for any number of varieties, t, and block size, k, most of the designs require too many replications for trial use (Cochran and Cox, 1957). When the numbers of replications are small (four or less) these designs cannot always be used.

Partially balanced designs lack the full balance shown in the designs above but have some symmetric properties, (i) each block contains k varieties and each variety occurs r times, but only once

in each block, (ii) every pair of varieties occurs together in either λ_1 (first associates) or λ_2 (second associate pairs) blocks, (iii) given two varieties that are i associates, the number of treatments is the same no matter which pair of the i associates is taken first (Cochran and Cox, 1957). The final property guarantees that designs with k associate classes only require k standard errors for testing differences between pairs of varieties. These designs do not, however, exist for all combinations of t and k. Further, many of the balanced and partially balanced designs are not resolvable. Resolvable designs have many important advantages over other designs in field trials and are to be preferred to non-resolvable designs.

Lattice designs were introduced by Yates (1936) for use in variety trials. These designs have two important characteristics: (i) that orthogonal sets of varietal contrasts are confounded with blocks in different super-blocks (replications) and (ii) that the designs are resolvable.

The first property makes the designs efficient and simplifies analysis. No other resolvable design gives a lower average residual variance than a lattice design with the same number of varieties, blocks (incomplete blocks) and super-blocks. Secondly, lattice designs cannot be less efficient than randomised complete block (RCB) designs since it is always possible to regard these designs as if they were ordinary randomised blocks (Yates, 1936). There are many practical advantages in using resolvable designs, one being that harvesting may be performed on the trial in parts, with each

part coinciding with a super-block (Yates, 1940).

However, there are limitations on the availability of lattice designs. If the number of varieties is a perfect square a design in two replications can be constructed, a square lattice. Triple and quadruple lattice squares (designs with three and four replications) are available but not for every value of k. Cochran and Cox (1957) give plans for balanced lattices. The special feature of these designs is that every pair of varieties occurs once in the same incomplete block so that all pairs of varieties are compared with the same degree of precision. Again, there are severe restrictions on the number of varieties and replications for which these designs are available.

Rectangular lattices, introduced by Harshbarger (1947), provide lattice designs for k(k-1) varieties. Rectangular lattices require more standard errors to measure variety comparisions and there is a greater variation in the precision with which variety means are compared than when comparisons are made in a square lattice. Square and rectangular lattices still do not provide designs for many combinations of k and r.

The availability of lattice designs was increased by Federer and Robson (1952) and for practical purposes completed by Patterson and Williams (1976) with the introduction of generalised lattice (GL) designs. Patterson, Williams and Hunter (1978) describe how GL designs can be generated and also recommend certain alternative designs. Williams, Patterson and John (1976) identify efficient

two-replicate designs which might be used when resources are limited.

GL designs have been used in cereal trials for about five years and have been found generally to increase precision, relative to randomised complete blocks. The median ratio of RMS_{RCB}/RMS_{GL} = 1.40 (RMS_{RCB}, is the residual mean square from the randomised complete block analysis, RMS_{GL} is the corresponding value from the generalised lattice analysis) Patterson and Silvey (1980), from trials with twenty or more cereal varieties indicate that a higher precision is attained from GL analyses than the RCB analyses.

Despite the wide availability of lattice and other designs for variety trials, lattice designs have not been used in potato trials. The type of design used in potato variety trials appears to have been limited almost exclusively to randomised complete block designs and split-plot designs (Killick, 1981).

Among other designs that could be applied to potato trials are row and column designs. Resolvable row and column designs, described by, among others, Haliburn (1980), have been used in cereal trials. These designs may not be so useful in potato trials since the spacial grid of potatoes is rectangular, rather than the square grid upon which cereals are grown. However, the value of these designs has yet to be tested with potato varieties.

The differences between cereals and potatoes and their respective husbandries do not permit the results from cereal trials to be

applied to potato trials. In 1979 and 1980 SPBS/PBI eight potato trials were laid out as GL designs. These trials were performed to investigate what gain in precision may be expected from using lattice designs in potato variety trials.

The eight trials performed to date are described in chapter 18. Use of GL designs appears in general to reduce the residual sum of squares and hence the error variance of the trial compared to a randomised complete block design analysis. The number of trials is still very small but the median ratio of $RMS_{RCB}/RMS_{GL} = 1.7$ for total yield is comparable to the same ratio from cereal trials. More trials using GL designs are necessary before firm conclusions can be drawn but the results so far are encouraging.

CHAPTER 4

Data Collected.

4.1 Introduction

The yield data collected for analysis were abstracted from NIAB record sheets and field note books and then adapted for mounting on the ICL 2980 computer of Edinburgh University. Data were available on 80 varieties from 33 sites during 1969-1978. These data were compiled from NIAB maincrop potato trials, the purpose of which was to evaluate the performance of new varieties prior to their possible inclusion on the Recommended List. A short description of NIAB trials and how the results may have been affected by the way in which the trials were conducted is given in chapters 1 and 2.

Note on NIAB trials.

Each year NIAB conduct trials to compare new varieties with established (control) varieties. The trials are designed to provide information on many characters of the varieties and these trials supply the data upon which the varieties are considered worthy to be put on the Recommended List. The trials are performed according to NIAB guidelines, but the trials do not form a strictly uniform series of trials, see Appendix II and chapter 1. A full description of the NIAB potato trial system is given by Richardson (1979). The data analysed in this thesis come from 4th, 5th and 6th years of the Recommended List Trials scheme, Table 5.

4.2 Data Analysed.

Data from 20 sites and 36 varieties have been analysed in detail. The remaining 44 varieties and 13 sites appeared infrequently in the trials, in some cases only once, and were excluded from the analyses, Tables 6 and 7. The sites and varieties which rarely occurred were omitted from the analysis since they contribute little information about variety x environment interaction. (A single occurrence of a variety or site contributes no information on variety x environment interaction.) Varieties tested only a few times are most likely to be those varieties that have some important defect, not necessarily in yield potential but probably in their botanical characters. The number of times each variety appears in trial is given in Table 6. The number of times each site is used is given in Table 7.

The 36 varieties and 20 sites included in the analysis give rise to 1948 means. The distribution of trials over regions, trial management (NIAB or ADAS) and soil type is summarised in Table 9.

As can be seen from Table 8 the reduced data set is still incomplete, i.e. not all varieties occur at each centre in every year. This imposes special requirements on the statistical analyses since the data are non-orthogonal.

4.3 Variate Analysed.

The variate analysed is total yield. Total yield is a less variable measure of the yield character of a variety than ware or saleable yield since the latter measurement can be considerably influenced by controllable environment effects, see chapter 1, and also by the definition of 'ware' yield chosen, see Appendix I. Use of the total yield measure gives an indication of the potential yield of each variety which is an important aim of field trials (French, 1981).

CHAPTER 5

Genotype x environment interaction.

5.1 Introduction

In variety testing, conclusions about the variety performance can only be made from data on phenotypic observations. Thus to make appropriate decisions on the value of the genotype the extent of the genotype x environment interaction must be known. The phenotype observed results from the variety and the interaction between the genotype and the environment. Since genotype x environment (G x E) interaction reduces the correlation between genotype and phenotype, inferences about the genotype made upon observations from the phenotype become difficult.

A plant breeder aims to obtain varieties that are high performing. Thus he can seek varieties that perform well over a wide range of environments (varieties with yields insensitive to environment) or varieties that are specifically adapted to yield well in certain environments (varieties with yields sensitive to environments). This first type of variety would have yields which display a low interaction with the environment and the latter type of variety would have yields which display a high interaction with the environment.

In the selection of varieties for the National List the magnitude of G x E interaction is important. If this interaction is large many trials, either over years and/or centres, will be required to collect data on the yields so that reliable decisions can be made. If the G x E interaction is small fewer trials will be necessary since all the trials will give similar results.

Both the breeder and the variety tester require estimates of G x E interaction so that they can plan their research or testing programme so as to achieve their goals as efficiently as possible. If G x E interaction is very small a testing scheme could be based (in the extreme case) on one trial, provided it had sufficient replication, but if the G x E interaction is large the testing scheme will have to be based on many trials. Thus it will be necessary to ascertain how many trials will be required to achieve a specified precision and how the trials should be distributed through the trial period, e.g. do 20 trials in one year give results of equal precision to 10 trials in two years ? Questions such as these can be answered by estimation of the interaction of the potato yield with the environment.

From the data collected in this study it is possible to derive components of variance; these components estimate the variance parameters which comprise the G x E interaction variance for total yield. This has been described, by, among others, Comstock and Moll (1963). These components, especially the variety x environment, variety x year and variety x environment x year components can be used to plan a future series of trials. In

particular it is possible to determine the optimum number of centres, replications and years that should be used.

5.2 Method

A specific series of experiments to investigate G x E interaction would be exceedingly expensive if adequate estimates are to be obtained. Replicated field trials are, however, commonly used to obtain estimates of the components of G x E interaction (Plaisted and Peterson, 1959, Patterson, Silvey, Talbot and Weatherup, 1977). Such trials give information on the varieties' performance over a series of years at several locations.

5.3 Analysis

Due to the non-orthogonality of the data the approach of Comstock and Moll (1963) for estimating the variance components cannot be applied directly. One method designed to estimate variance components from incomplete data is a restricted maximum likelihood technique described by Patterson and Thompson (1975). The method maximises the joint likelihood of all contrasts with zero expectation. The theory of this method is given by Patterson and Thompson (1971 and 1975).

5.4 Partitions of the data

The size of the data matrix, 36 x 20 x 10 (36 varieties, 20 sites, 10 years) prevented the entire data set from being analysed as a whole. Thus the data were partitioned into subsets that could be operated upon by the computer.

The data were analysed in several different sub-divisions. In one division the trials were divided into trials at NIAB centres and trials grown by ADAS. The NIAB trials are repeated at the same centres in consecutive years, though in different fields. The ADAS trials are, in general, on commercial farms and so provide a large sample of soil conditions, Table 9. In a more natural division the sites are grouped by some physical feature. One such division is by the type of soil on which the trial was grown. The soil type has not been recorded in every case but where the trials at a centre have been grown on a similar soil type for several years a soil class has been assigned to that centre, Table 9. The NIAB definitions of soil type have been used and these appear in Table 10. Another division of the sites is by location. England is divided into regions by NIAB, and these regions were used to group the sites by location, Table 9 and Diagram L. There are two eastern regions, two western regions and one northern region in which potato trials are grown.

The sizes of the partitioned and full data sets are given in Table 8.

These divisions employ two natural characters of the sites and one physical feature of the sites, all of which may alter the G x E interaction estimated.

5.5 Interpretation of variance components.

The following variance components were estimated by restricted maximum likelihood:

$$\sigma^2_{VY}\ ,\ \sigma^2_{VC}\ ,\ \sigma^2_{VCY}\ ,\ \text{and}\ \sigma^2_{\varepsilon}\ .$$

The σ^2_{VC} component arises from differences in conditions at the centres, irrespective of years. σ^2_{VY} arises from differences between seasonal conditions affecting all centres. σ^2_{VCY} is the total variance due to localised effects, i.e. some seasonal changes affect the centres unequally and some differences between centres will be increased in some years but not in others. The plot error variance, σ^2_{ε}, is due to (i) errors in measurement, (ii) differences between replications within a single experiment and (iii) individual characters of plants and plots. The estimated values of these variances (for total yield) for each data set are given in Table 11.

Standard errors (SE) of estimated variance components are large, in some cases the SE is more than half as large as the estimated variance.

The hypotheses that σ^2_{VC} and σ^2_{VY} are zero are rejected at the 5% level.

Two sets of variance components for ADAS sites are given for 1974-1978. In 1969-1973 eight ADAS sites were used. In 1974-1978 trials were grown at two more sites than in the previous five years, so the components of variance arising in the two quinquennial periods are not strictly comparable. Thus a second analysis was performed for 1974-1978 using data from only those sites common to both quinquennial periods. The change in the σ^2_{VCY} standard error could suggest that the two new sites have differing local effects from the other sites.

5.6 Effect of drought years.

The drought years, 1975 and 1976, increased the spread of the variances in the second quinquennial period compared to the first. This indicates that the years from which the data are collected influence the the estimated components.

Omission of the 1976 data from the analysis produces a slightly lower σ^2_{VC} (4.803 ± 1.894) and σ^2_{VY} (0.981 ± 1.247) for the NIAB centres compared to when 1976 was included, Table 11. For the ADAS sites the σ^2_{VY} is again estimated as zero but σ^2_{VC} is slightly larger

(5.008±4.000). Although the differences in the analyses, with and without 1976 data, are not significant, the results do change in the expected direction.

The mean yield of the second quinquennial period (1974-1978) is about 2.0t/ha below that for 1969-1973. This lower value can be explained by the poor yields in 1976 alone; deletion of that year's data increases the mean yield to about 1.0t/ha above that for 1969-1973.

5.7 The contribution of the variance components to the total variety x environment interaction variance.

The relationship between the variance components and the number of centres, years and replications to the total variety x environment interaction variance (V) is given by:

$$V = \frac{\sigma^2_{VY}}{n} + \frac{\sigma^2_{VC}}{m} + \frac{\sigma^2_{VCY}}{n.m} + \frac{\sigma^2_{\varepsilon}}{n.m.r}$$

where V = total variety x environment variance

σ^2_{VC} = variance of the variety x centre component

σ^2_{VY} = variance of the variety x year component

σ^2_{VCY} = variance of the variety x centre x year component

σ^2_{ε} = variance of the error component

m = number of centres at which varieties are tested

n = number of years a variety is in trial

r = number of replications in a trial.

The largest variances arise from σ^2_{VCY} and σ^2_{ε}, Table 11. However, in

the calculation of V, σ^2_{VCY} and σ^2_{ε} are divided by the larger denominators, hence their contribution to V diminishes rapidly as m and n are increased.

If one trial is performed σ^2_{VCY} is the major contributor to V, Tables 12, 13 and 14. To decrease V most readily the number of centres can be increased. Increasing m does not decrease the contibution of σ^2_{VY}, this can only be decreased by increasing n. An increase in n has a greater effect in reducing V than increases in m. An increase in r has little effect on V, Table 15.

Re-distribution of fixed trial resources can alter the variance attainable in a trial system. Twenty trials used in one year gives a higher variance than ten trials used in two years; further, ten trials used for two years gives a lower V than thirty sites in one year, Table 15.

5.8 Critical Differences.

Critical differences can be used to measure the precision attained by different trial procedures. The critical percentage difference is the value that must be exceeded by the percentage difference between a single test variety and the mean of, for instance, two control varieties, if the test variety is to be accepted.

Combination of the information from the analyses concerning the NIAB and ADAS sites enables the variance components for the entire data set to be obtained. From these variances critical differences (CD) in the yields of the potato trial system can be determined, (Patterson et al 1977).

5.9 Estimated Critical Differences.

Table 16 gives the critical differences measured between one test variety and the mean of two control varieties when components of variance estimated from the entire data set are used. The underlined figure in Table 16, 6.1%, is the critical percentage difference of the present NIAB trial system where a variety is tested for three years at twenty sites.

5.10 Discussion.

The main use of estimated critical differences is to assess changes in precision that may be expected to result from changes in the length of trial period, the number of sites and replications used.

Table 16 shows that the number of years over which the varieties are tested has the greatest effect on trial precision. Once 15 centres have been employed additional centres have little effect on the critical difference and unless an impractically large number of centres are to be used the only way that a large increase in precision can be obtained is by increasing the number of years over

which the trials are grown.

The critical differences given in Table 16 refer to only the precision resulting from successful trials. Thus the figures give only expected precisions from trial systems.

In many cases in these data the test varieties do not appear at all 20 centres each year, so the present trial system may have a lower precision; the critical difference could be closer to 7.1%, the difference arising from using ten centres for three years.

5.11 Acceptance Probabilities.

A second measure of the precision of a trial system is that of acceptance probabilities. Acceptance probabilities, α, for any given critical difference, can be calculated for various trial regimes (Patterson et al, 1977) so enabling comparisons between different trial systems. These probabilities are given by F(x).

F(x), is the probability that a variate's value lies below x in the standard Normal distribution, where,

$$x = \frac{1.96(\delta - 2.5)}{d(0.05)^2}$$

where δ is the true mean difference,

2.5 is the critical percentage difference

5.12 Results

Table 16 can be used in the calculation of F(x), and the values of F(x) for several trial regimes appear in Table 17. A reliable trial system should have a low probability of accepting a variety which yields less than the control varieties and a high probability of accepting a variety which outyields the control varieties. The ideal trial system would have acceptance probabilities of the form:

	Variety mean yield (as % of control mean) CD = 2.5% of mean of two controls		
	100%	102.5%	105%
Probability of acceptance	0.0	0.5	1.0

whereas the trial regimes in Table 17 exhibit the 'real' acceptance probabilities. Each system has a higher probability of accepting a variety with a yield less than 102.5% of the controls and a lower probability of accepting a variety with a yield greater than 102.5% than an ideal trial system.

5.13 Discussion

The present system, system A, uses 20 sites for 3 years. Consider a system B, using 15 sites for 3 years, a system C using 20 sites for 2 years and a system D using 30 sites for 2 years. Suppose all the systems use two control varieties and four replications per trial; the sites are drawn from both ADAS and NIAB sites. In each system a critical difference of 2.5% has been chosen. (A variety is accepted if its mean yield is 102.5% or more of the mean yield of two control varieties.) Table 17 gives the acceptance probabilities in each trial system. As can be seen from

Table 17 these probabilities are greater than the ideal probabilities for values below the true mean difference and less than the ideal probability for values above the true mean difference.

System A is the system most likely to accept varieties that outyield the control varieties and reject varieties which fall short of the controls' mean yield. The two systems, A and B, which test the varieties over three years give acceptance probabilities closer to the ideal than the systems that test over two years.

System A requires $(n + 2) \times 4 \times 20 \times 3$ plots to test n varieties or $(n + 2).240$ plots,

system B requires $(n + 2).180$ plots,

system C requires $(n + 2).160$ plots, and

system D requires $(n + 2).240$ plots.

Although systems A and D require the same number of plots to test n varieties system A would be expected to give the more precise results, but D has the advantage of reducing the number of years of trials by one. Systems B and C require fewer plots than A or D, but the precision in systems B and C is less than that from system A.

Any economies that might be made which involve a reduction in the number of trials, either by reduction in the number of centres or years, must not be considered divorced from the loss in precision which results in a reduced trial system.

The difference in acceptance probabilities between A and D show the importance of testing over years to gain precise results. A and D both require the same number of plots and the difference in precision arises from the way in which the trials are distributed over time.

5.14 Comparison of ratios of estimated variance components.

Table 18 gives the estimated variance components from a selection of crops. As the size of the variance components depends upon the magnitude of the yields measured the variance components are difficult to compare. To remove this difficulty ratios of the variance components are considered, Table 19. The components have been divided by σ^2_{VC}, thus the ratios compare each component to the variation arising between centres irrespective of years.

5.15 Results.

The components estimated come from a diverse selection of papers for a range of crops, grown at different places and times. Not all the papers have dealt with such a large data set as this study, e.g. Sekioka and Laur (1970) considered three potato varieties at four centres from only five years' data.

The ratio $\sigma^2_{VY}/\sigma^2_{VC}$ has been considered in preference to other ratios because the relative sizes of these two components is important in determining the form of the trial system that should be used for that crop. The range of ratios for the same crop is often

large, e.g. in the case of wheat $\sigma^2_{VY}/\sigma^2_{VC}$ = 0.108 to 4.6326 and Barley, 0.44 to 18.14 . In the case of potatoes the range is 0.00 to 0.99.

5.16 Discussion

The range of the ratio $\sigma^2_{VY}/\sigma^2_{VC}$ from potato investigations is much smaller than compared to other crops. The estimates of Sekioka and Lauer (1970) may be unreliable due to the small size of the data set. If the results from this 1970 analysis are ignored, the ratios for potatoes are remarkably similar, with estimates of $\sigma^2_{VY}/\sigma^2_{VC}$ between 0.88-0.99.

This consistent aspect of the potato may not seem so remarkable if only the estimates from wheat 8 and 6 in Table 19 were available, since these two studies give more similar ratios. However, Table 19 is important in that it shows that potatoes are not outstandingly different to other crops in the way in which years and centres affect the potato rank orders. The fact that the potato appears in the centre of Table 19 indicates that the potato is far from being distinctive in the way it is affected by years and centres compared to other crops.

CHAPTER 6

Analysis of residuals.

6.1 Introduction

Examination of residuals from a fitted model can provide a useful way of detecting values that deviate more than other points from the estimated values. A number of tests for detecting outlying values have been devised (e.g. Draper and John (1980), Gentleman and Wilk (1975)); here we use a test due to John and Prescott (1975) and a graphical method.

Each variety x centre table was screened for values which may be considered as outlying. Identification of such values might help to point out important variety x environment interactions. Much of the interaction present in a variety x centre table may be due to a few values.

6.2 Method.

The residuals, after removing the environment and variety effects by the use of an additive model such as FITCON (described in 6.6), were ordered and plotted against the quantiles of the standard Normal distribution (QSND). If this graph results in a straight line then the residuals follow a Normal distribution. A heavy-tailed plot can indicate, (i) non-Normality, (ii) skewness in the distribution and (iii) the presence of interaction. A point detached from the line so that it does not lie on the same contour as the others suggests that the observation giving rise to this

residual may be an outlying value.

Replacement of this observation by its estimated value enables the effect of the deleted observation on the residual sum of squares to be assessed. A plot of the revised residuals also indicates the effect of deleting the outlying observation.

A test, described by John and Prescott (1975), was used to examine the effect of deleting certain observations.

$$s = \frac{RSS - mRSS}{mRSS/(n-1)}$$

$$s \sim F_{1,n-1}$$

where RSS is the residual sum of squares before the observation was deleted and replaced by its missing value estimate,

mRSS is the residual sum of square after the observation has been replaced by its missing value estimate.

n is the degrees of freedom (df) associated with the residual mean square before the observation was deleted.

The value of s calculated is compared to the P/N point in the F-tables, where P is the percentage point for the test and N is the number of observations in the table. If s exceeds F then the deleted observation is considered to be an outlying value. If a second point is regarded as being an outlier, then both the first and second points are deleted and the new estimated values obtained. The new mRSS is calculated and the test repeated.

6.3 Results.

The list of outlying values detected by the test above and visually through the plotting of ordered residuals is given in Table 20. Cara and Estima appear most often in this list; outlying values are most frequent in the SW and WC regions. All the SW sites appear in this list of sites but only one site from EC. Harper Adams appears twice in 1973 and 1977; which suggests that this site is particularly variable.

6.4 Residuals as indicators of variety yield adaptability.

For a variety to be of value over a wide range of conditions it must be able to adapt to many different environments in order to produce a high yield.

A variety that is specifically adapted to good environments will give higher yields than expected on good environments but lower than expected yields on poor environments. The reverse pattern of yields emerge for a variety that is specifically adapted to low yielding environments. A variety that is able to adapt to a range of environments will give high yields irrespective of the environment. The residuals from the fitted model are used to examine variety adaptability to different environments.

6.5 Discussion.

The outlying observations arise from consistent results from the trials; in no instance can the yield from any single block of the trial be regarded as particularly variable. For example, Désirée and Estima gave the following yields at Harper Adams in 1973,

	Block 1	Block 2	Block 3	Block 4	
Désirée	72.1	73.0	70.5	78.9	yield in t/ha
Estima	92.4	94.6	84.0	92.8	
Block mean	58.8	58.8	58.2.	63.8	

This example shows that the mean yields at this site arise from a genuine interaction, and not from variable yields. The highest residuals in some tables can be accounted for by the sensitivity of the variety's yield to the environment on which the variety is grown. The model:

$$y_{ij} = v_i + I_j$$

is modified to introduce a variety sensitivity parameter, β_i,

$$y_{ij} = v_i + \beta_i I_j$$

where y_{ij} is the yield of variety i at environment j, v_i is the mean yield of variety i, and I_j is the effect of environment j. In 1975 the high residuals associated with Cara and Paragon can be explained by the fact that Cara's yield is very insensitive to environments and Paragon very sensitive. If the residuals are re-examined after variety yield sensitivities have been allowed for, the values of Cara and Paragon formally identified as outlying are no longer found. This is illustrated in Graphs 1 and 2. A similar analysis

on the 1977 data does not account for the outlying values previously detected, Graphs 3 and 4. In 1973 the high residual of Estima at Harper Adams is considerably reduced when Estima's yield sensitivity is accounted for, however the outlying values in the data set are still unexplained after yield sensitivity has been allowed for.

There seems to be no botanical reason why these particular varieties interact with these environments to such an extent, Simmonds (1981). Any explanation due to, for instance, use of cut seed to make up a seed shortage would be mere conjecture so long after the trials were performed. Unusual departures from standard practice should be recorded in the field notebooks.

Coefficients of variation (CV) are generally higher in WC than in other regions. Since WC sites have a higher mean yield than other regions, Table 14, the higher CVs at WC sites must be due to their larger variances. The higher variability of WC sites may explain why most outlying values are found in this region, Table 21.

6.6 Fitted Constants.

This technique, described by, among others, Patterson (1978), adjusts the simple mean yields of the varieties in the variety x centre table for the environments at which the varieties do not occur. Hence if a variety only appears at high yielding environments its simple mean yield will be reduced, whereas a variety which only appears at low yielding sites will have its mean yield increased.

The fitted constants model is:

$$y_{ij} = v_i + I_j$$

where y_{ij} is the yield of variety i at site j

v_i is the mean yield of variety i

I_j is the effect of the j^{th} environment,

Use of fitted constants (FITCON) enables comparable variety mean yields to be obtained from incomplete data sets.

Examination of residuals arising from use of this model on the variety x centre table can indicate a variety's yield sensitivity. A variety that has positive yield residuals at low yielding environments and negative residuals at high yielding environments is considered an insensitive variety. A variety's yield which produces a pattern of residuals opposite to that described above is sensitive to environments. If neither pattern of residuals is produced the variety has average sensitivity.

The FITCON model was applied to each of the variety x centre tables, the residuals arising from two analyses appear in Tables 22 and 23. The environments have been ordered, with those having the smallest environment effect to the left of the table.

6.7 Results - Variety environment adapability.

For many varieties there is no simple pattern of residuals. Most varieties have positive and negative residuals throughout the range of environments. However, the pattern is often sufficently clear to

indicate the adaptability of a variety. Tables 22 and 23 give residuals from FITCON (multiplied by 10) for 1975 and 1978 respectively. In 1975 (Table 22) a drought year, Pentland Crown has positive and negative residuals throughout the environment range. This suggests that Pentland Crown's yield is not specifically adapted to any particular environment. This variety contrasts with the pattern of residuals from Cara and Paragon. The former variety's residuals suggest the variety yield is insensitive to environment (negative residuals at high yielding sites) and the latter variety's yield is sensitive to environment (positive residuals at high yielding sites). In 1978 (Table 23) 916/4 has all its positive residuals at the lower yielding sites which suggests that this variety is adapted to lower yielding sites.

The pattern of residuals for a particular variety can be quite different each year, which illustrates the variable nature of the way a variety responds to environments each year. In 1975 (Table 22) King Edward tends to have more negative residuals at higher yielding sites but in 1978 (Table 23) it has most negative residuals at lower yielding sites.

6.8 Results - Variety x region adapability.

The pattern of the residuals can also indicate if a variety's yield is favoured by particular regions. In Tables 24 and 25 the sites have been ordered by region, and within each region the lowest yielding sites to the left. Many varieties do not display a consistent pattern of residuals within a region. The varieties that

do have a consistent pattern of residuals include Croft, Drayton, and Estima which have five negative residuals from the six EE sites, in 1976, Table 25. 1225A3 has five positive residuals at EE sites, and all its residuals negative at EC sites, in 1976, Table 25. In 1973, Table 24, a much wetter year than 1976, Table 38, Drayton has positive residuals at EE sites, the reverse of its pattern in 1976. In 1976, a year of low rainfall, Pentland Crown has no pattern to its residuals in any region. In 1973, a much wetter year, Pentland Crown tends to have its negative residuals at wetter regions and positive residuals at drier regions, Table 24. This pattern could be expected from Pentland Crown, which is a reputed drought resistant variety.

6.9 Discussion.

The tables of residuals from the FITCON analysis illustrate the variation in potato trial yields within a year and within a region. Interaction of variety x environment is measured by the residual mean squares (RMS) from the analysis compared to the plot error. Thus, in 1976 the RMS of 25.36 was 5.5 times the plot error mean square of 4.58.

If detailed site information was available for each trial it might be possible to explain some of this yield variation, but for many sites little information was recorded. Some varieties produce high residuals at some sites, which indicate either a high degree of interaction or possibly errors in measurement or recording. These unusual yields have already been considered in 6.1.

EX BIBL UNIV. EDINBURGEN

CHAPTER 7

Estimation of variety sensitivity.

7.1 Introduction

Cochran and Yates (1938) introduced the idea of examining variety variability by regressing the variety yield against the mean environment yield. This idea has been taken up more recently, by, among others, Finlay and Wilkinson (1963). The effect of environment is measured by the average yield of all the varieties grown at that environment. Because the individual variety yields are plotted against the mean of all the variety yields the population mean has a regression coefficient of 1.00.

7.2 Interpretation of yield sensitivity parameters.

Regression coefficients greater than 1.00 are associated with varieties that are sensitive to environment changes and have a greater specificity of adaptability to high yielding environments. For instance, these varieties do well on favourable environments but poorly on unfavourable environments.

Regression coefficients less than 1.00 are associated with varieties which are insensitive to environment changes and these varieties are considered to have a lower specificity of adaptability to high yielding environments, i.e. the yield of these varieties is fairly constant irrespective of the type of environment.

7.3 Regression model.

Finlay and Wilkinson (1963) fitted a model of the form:

$$y_{ij} = v_i + \beta_i y_{.j}$$

to describe the yield performance of a variety over a series of environments, where,

y_{ij} is the yield of a variety i , at the j^{th} environment

v_i is the mean yield of variety i over all the environments

β_i is the regression (sensitivity) coefficient of variety i

$y_{.j}$ is the mean yield at environment j .

Finlay and Wilkinson (1963) applied the method only to data sets where the variety x centre table is complete. The method must be modified to deal with incomplete data sets. This can be done by calculating regressions on the environment constants of the FITCON analysis (Patterson and Silvey, 1980).

7.4 Modified Regression analysis.

An alternative method of computing these regression coefficients from incomplete data is AUGFITCON, described by Patterson and Silvey (1980), and is the method used here. Digby (1979) gives full details; he refers to the method as Modified Joint Regression Analysis. This method modifies the fitted constants technique which

does not allow for differences in variety yield response ($\beta_i = 1$) to environment effects. AUGFITCON aims to do this by fitting a model of the form,

$$y_{ij} = v_i + \beta_i I_j$$

Where I_j is the environment effect. The calculation of AUGFITCON is an iterative method which estimates the β_i starting from the initial assumption that all the β_i are the same and equal to 1.00, as in FITCON (Digby, 1979).

7.5 Estimation of β_i, the yield sensitivity parameter.

The modified joint regression model (AUGFITCON) was applied to the ten variety x centre data tables and the variety yield sensitivity ($\hat{\beta}_i$) parameters calculated, Table 26. Each sensitivity parameter is based on a minimum of five trials.

7.6 Estimated β_i

Table 26 illustrates the inconsistency of the yield sensitivity parameters from year to year for a particular variety. Some varieties have a similar yield sensitivity estimate over years but many varieties exhibit a range of estimates of β_i. The variances associated with the $\hat{\beta}_i$ are quite large and make the results difficult to interpret.

The test of main interest is whether or not a sensitivity parameter is significantly different from 1.00. The hypothesis about β_i can be made using the t-distribution. To test whether or

not β_i is consistent with a theoretical value of $\beta_o = 1.00$, the test statistic is :

$$t = \frac{\beta_i - \beta_o}{(\mathrm{Var}(\beta_i))^{\frac{1}{2}}}$$

t has a t-distribution with n-2 df, (Sprent,1969).

The few values of $\hat{\beta}_i$ which are significantly different from 1.00 are marked in Table 26. Cara, $\hat{\beta}_i$ consistently less than 1.00, and S62471, $\hat{\beta}_i$ consistently greater than 1.00, are the only varieties about which firm inferences can be made. Some varieties, e.g. Pentland Squire, have $\hat{\beta}_i$ significantly greater than 1.00 in one year and significantly less than 1.00 in another year, which highlights the inconsistency of the $\hat{\beta}_i$.

Despite these inconsistencies the values of $\hat{\beta}_i$ estimated for each variety give an indication of the variety sensitivity. i.e. A $\hat{\beta}_i$ always greater or less than 1.00 suggests that variety yield is respectively sensitive or insensitive. King Edward and Majestic, however, produce $\hat{\beta}_i$ estimates that do not lie consistently either side of 1.00.

7.7 Influences upon estimated values of $\hat{\beta}_i$.

The year does not appear to have a constant effect on the $\hat{\beta}_i$ obtained for certain varieties, e.g. HO/48; estimates for β_i are in 1970, 1972, 1973, $\hat{\beta}_i$ = 0.74, 0.79, 0.80 and in 1974, 1975 $\hat{\beta}_i$ = 1.03, 1.04. 1970, 1973, 1974 were generally higher yielding years, 1972

an average yielding year and 1975 a lower yielding year. Thus it is not possible to simply relate a below-average yield sensitivity with a low yielding year, or vice versa.

The defect of inconsistent yield sensitivity parameters may be due to the set of environments from which they are estimated. Year effects cause sites to behave differently each year but if different sites are used each year the differences between site changes due to year and the different sets of sites will be confounded.

The environment effect is measured by the particular varieties grown. If a different set of varieties is grown each year (except the variety whose yield sensitivity is to be measured) then the test variety's yield may appear to be either sensitive, or insensitive depending on how the other varieties behave.

Thus there are three main factors which may explain the variability of $\hat{\beta}_i$:

(i) the environments on which the variety is grown,

(ii) the group of varieties with which the variety is grown,

(iii) the year in which the estimate is made.

7.8 Analysis of year, variety and site upon $\hat{\beta}_i$.

To examine effects of year, environment and varieties on the estimates of yield sensitivities the following analysis was performed.

Seven varieties grown at ten sites for three years were considered. The varieties and sites were the same for each year. The AUGFITCON estimates of β_i from each data set appear in Table 27.

The AUGFITCON analysis was repeated using the same set of ten centres with the same seven varieties used in the first analysis and three additional varieties, Table 28.

The AUGFITCON analysis was repeated again, with the data set used in the first analysis and data from four additional sites, Table 29.

7.9 Results.

In Table 27 the point estimates for β_i for some varieties vary considerably, by 0.63 in the case of variety V5, and for several varieties the range is of the order 0.2-0.3; so the year in which the estimates are made has a large effect on the point estimate. Varieties with yields that appear insensitive to environments in one year, V5 in 1976, may be sensitive in another year, V5 in 1974.

As can be seen from Table 29 centres have little effect on the estimated β_i. The largest difference between any two point estimates is 0.14.

Table 28 shows the presence of a different set of varieties has little effect on $\hat{\beta}_i$. Inclusion of another three varieties in the

analysis produces no difference between the point estimates greater than 0.10.

Tables 27, 28 and 29 indicate that the year has the greatest effect on the estimate of yield sensitivity compared to centres and varieties. None of the data sets in 1976 show any $\hat{\beta}_i$ to be different from 1.00. In 1975 one variety had $\hat{\beta}_i$ significant at the 10% level. In 1974 two varieties have $\hat{\beta}_i$ significantly different from 1.00 at the 10% and one at the 5% level when seven varieties are analysed; when 10 varieties are considered only one $\hat{\beta}_i$ is significant at the 10% level.

If significant deviations from 1.00 are of major interest then this analysis indicates that varieties which deviate considerably from 1.00 will be found, within a given year, from different data sets.

7.10 Sensitivity of variety yield to differences between years.

Years may be considered as a set of environments and the 'environment' or year effect can be measured by variety mean yields. The AUGFITCON model was applied to 10 years data on 11 varieties. The results of the analysis appear in Table 30.

7.11 Results.

Some varieties that have $\hat{\beta}_i$ values consistently one side of 1.00 for the within years yield sensitivity (sensitivity of yield to

environment differences) give a $\hat{\beta}_{iy}$, sensitivity over years, (i.e. sensitivity of yield to differences between years) the opposite side of 1.00, e.g. Pentland Crown. Other varieties, however, give a similar value of $\hat{\beta}_i$ as the $\hat{\beta}_{iy}$, e.g. Record. Majestic and King Edward, which both produce inconsistent $\hat{\beta}_i$, give β_{iy} estimates close to 1.00, which suggests that they are of average yield sensitivity. The low value of $\hat{\beta}_{iy}$ associated with Pentland Crown indicates its yield is insensitive to differences over years. This β_{iy} estimate, coupled with a high overall mean yield shows that Pentland Crown can be expected to give high yields in most years.

A test of $\beta_{iy} = 1.00$ can be made via a t-test in the same way that β_i was tested. Estima is found to have yields sensitive to year effects (at the 5% level) and Stormont Enterprise to have yields insensitive to year effects (at the 10% level). No $\hat{\beta}_{iy}$ from other varieties, in Table 30, are found to differ significantly from 1.00. Although varieties such as Pentland Crown and Désirée have $\hat{\beta}_{iy}$ less than 1.00, as would be expected from drought resistant varieties, the estimates of $\hat{\beta}_{iy}$ are not significantly less than 1.00, thus neither variety can be said to have yields insensitive to year effects.

7.12 Discussion.

The results from these data suggest that the $\hat{\beta}_i$ are dependent upon the year for which they are estimated. However, for this study the standard errors are such that few β_i estimated for the same variety can be considered different from 1.00 even though the point estimates may considerably, e.g. 0.46 to 1.2 for Pentland Raven.

For some varieties $\hat{\beta}_i$ appears to be related to rainfall in the growing season. For a variety such as Oakpark Amber $\hat{\beta}_i$ increases with increasing rainfall and for another varieties such as Estima the reverse effect occurs. In Table 26 the wettest years appear at the bottom of the table. Other varieties, such as Pentland Crown, display no such simple relationship between estimated β_i and rainfall. The majority of the varieties fall into the Estima class of variety, with yield sensitivities that decrease as the rainfall decreases, or into the Pentland Crown class.

Extreme values of $\hat{\beta}_i$ obtained may be found in the wettest or driest years but the $\hat{\beta}_i$ are rarely significantly different from 1.00. If a strong link exists between $\hat{\beta}_i$ and rainfall, the $\hat{\beta}_i$ which deviate significantly from 1.00 would be found either towards the top (dry years) or bottom (wet years) of Table 26.

Although these observations on $\hat{\beta}_i$ and rainfall may help to suggest an explanation of the different yield sensitivities for a given variety, this result does not help in the examination of β_i associated with a given variety. Which values of $\hat{\beta}_i$ in Table 26 most closely estimates β_i, for Pentland Crown, for instance? A relationship between rainfall and $\hat{\beta}_i$ indicates that there is perhaps no fixed sensitivity for a variety, in which case a yield sensitivity should only be given under specified conditions.

More reliable estimates of β_i are to be expected from use of a wider range of environment effects than a narrower one. Few $\hat{\beta}_i$ show a simple relationship with the variance of the environment effects.

For some varieties $\hat{\beta}_i$ decreases for decreasing environment effect variance (DHS/21), and other varieties show the opposite effect, such as Estima. This result implies that the range of environment effects from which β_i is estimated has generally no consistent effect on the value of $\hat{\beta}_i$ obtained, see chapter 16.

7.13 Comparison of β_i estimated from agricultural and trial data.

The $\hat{\beta}_i$ from trials have been criticised since they differ from similar estimates from agricultural data (Simmonds, 1980). Simmonds points out that Majestic and Pentland Crown are 'reliable' varieties and that King Edward is a 'fussy' variety. The median estimates of β_i in Table 26 are in poor agreement with the β_i estimated from agricultural data for Pentland Crown and King Edward, but fairly good agreement for Majestic ,Table 31.

The results presented by Simmonds (1980) suggest that since Pentland Crown has a low sensitivity and a high mean yield it is unlikely to be out-yielded on either the high or low yielding environments. Thus Pentland Crown should out-yield most varieties in any environment. Our trial data suggest this is not so. The data used in this thesis contain many examples where Pentland Crown is out-yielded at the lower and higher yielding environments. For example in 1975, for Cara $\hat{\beta}_i$ = 0.3, for Pentland Crown, 1.1 and Paragon 1.4, at the extreme yielding sites Pentland Crown is not superior to the other varieties, Graph 5.

Simmonds (1980) found that the yield sensitivities between and within years did not disagree for trial data, but did disagree from agricultural data. The yield sensitivities between and within years estimated from the trials studied here suggest differences between the two parameters. For example, Pentland Crown $\hat{\beta}_{iy} = 0.87 \pm 0.11$ which contrasts with $\hat{\beta}_i = 1.00$ in Table 26. Similar differences between $\hat{\beta}_i$ and $\hat{\beta}_{iy}$ have been found for cereals, see discussion following Patterson and Silvey's 1980 paper.

The mean yields estimated from trial and agricultural data suggest different rank orders of the varieties. The difference between variety yields is greater in the agricultural data. Although our data sample different years from those of Simmonds we both obtain the same variety ranking for yield, King Edward < Majestic < Pentland Crown, which contrasts with the ranking from agriculture, Majestic < King Edward < Pentland Crown.

The variate considered by Simmonds (1980) was yield of tubers over 41.3mm, not total yield, and the different variates analysed may account for differences between the two sets of results.

CHAPTER 8.

Regression analysis and singular value decomposition.

8.1 Properties of SVD.

The properties of the singular value decomposition (SVD) of a matrix have been described, by among others, Good (1969).

When $\underline{M}$ is a real m x n matrix of rank k, it may be written as the sum of k matrices of rank one by its singular decomposition:

$$\underline{M} = u_1 \underline{m}_1 \underline{n}_1' + u_2 \underline{m}_2 \underline{n}_2' + u_3 \underline{m}_3 \underline{n}_3' + \ldots + u_k \underline{m}_k \underline{n}_k'$$

where the column vectors $\underline{m}_1 \ldots \underline{m}_k$ are orthogonal, of unit length and each has m components; the row vectors $\underline{n}_1' \ldots \underline{n}_k'$ are also orthogonal, of length one and each has n components. The numbers $u_1 \ldots u_k$ are real and positive and are the square roots of the positive latent roots of $\underline{M}'\underline{M}$ or $\underline{M}\underline{M}'$, each of which is a symmetric square semi-positive definite matrix. The vectors $\underline{m}$ and $\underline{n}$ are latent vectors of $\underline{M}\underline{M}'$ and $\underline{M}'\underline{M}$ respectively. $u_1 \ldots u_k$ are the singular values of $\underline{M}$ and the vectors $\underline{m}_1 \ldots \underline{m}_k$, $\underline{n}_1 \ldots \underline{n}_k$ are the right and left singular vectors.

8.2 Relationship between the regression model and the spectral decomposition of the variety x centre table.

When the data set is complete the regression model:

$$y_{ij} = \mu_i + \beta_i I_j + \varepsilon_{ij} \qquad (1)$$

where y_{ij} is the yield of variety i at site j

μ_i is the mean of variety i

β_i is the sensitivity parameter of variety i

I_j is the environment effect of site j,

gives identical estimates for β_i and I_j as the spectral decomposition of $\underline{Y}$. i.e. the model fitted would be of the form:

$$\underline{Y} = \theta_1 \underline{u}_{1i} \underline{v}'_{1j} + \theta_2 \underline{u}_{2i} \underline{v}'_{2j} + \ldots \quad (2)$$

where: $\underline{Y}$ is the matrix whose ij^{th} element is $y_{ij} - \mu_i$

θ_1 is the first singular value

$\underline{u}_{1i}$ is the left latent vector corresponding to θ_1

$\underline{v}'_{1j}$ is the right latent vector corresponding to θ_1

This can be shown as follows:

Consider the model,

$$y_{ij} = \mu_i + \theta\beta_i I_j + \varepsilon_{ij} \quad \text{with } \Sigma I_j = 0$$

$\Sigma I_j^2 = \Sigma \beta_i^2 = 1$, as side conditions,

θ is a constant.

$i = 1, \ldots n$

$j = 1, \ldots p$

ε_{ij} an error term

y_{ij} is the yield of variety i at site j

$y_{i.}$ is the mean yield of variety i over all sites

$y_{.j}$ is the mean yield of site j of all varieties.

The method of least squares requires,

$\Sigma_i \Sigma_j (y_{ij} - \theta\beta_i I_j - \mu_i)^2$ to be minimised.

The normal equations are:

$$\sum_j (y_{ij} - \theta\beta_i I_j - \mu_i) = 0 \qquad \text{(i)}$$

$$\theta\sum_i \beta_i(y_{ij} - \theta\beta_i I_j - \mu_i) = 0 \qquad \text{(ii)}$$

$$\sum_j I_j(y_{ij} - \theta\beta_i I_j - \mu_i) = 0 \qquad \text{(iii)}$$

These equations give:

$$\beta_i\theta^2 = \sum_k \sum_j \beta_k(y_{kj} - y_{k.})y_{ij}$$

$$= \sum_k \sum_j \beta_k(y_{kj} - y_{k.})(y_{kj} - y_{k.})$$

If $t_{ik} = \sum_j (y_{ij} - y_{i.})(y_{kj} - y_{k.})$

$$= \sum_j y_{ij}y_{kj} - py_{i.}y_{k.}$$

$$\beta_i\theta^2 = \sum_k \beta_k t_{ik}$$

$\beta\theta^2 = \underline{T}\underline{\beta}$ since $\underline{T}\underline{\beta}$ has i^{th} element $\sum t_{ik}\beta_k$, thus θ^2 is a latent root of $\underline{T}$ whose typical element is t_{ik}. If I_j had been eliminated θ^2 would have been found to be the latent root of a matrix $\underline{U}$ which has the same latent roots as $\underline{T}$ and $p-n$ zero roots if $n < p$, and one zero root otherwise. If θ_i^2 are the latent roots of $\underline{T}$ then the residual sum of squares (RSS) after fitting model (2) with one interaction term is: $RSS = \sum_{i=1}^{i} \theta_i^2 - \theta_f^2$

where θ_f^2 is the latent root of the interaction term in model (2).

For the residual sum of squares to be a minimum θ_f^2 must be the largest latent root, so θ_f^2 must be the first latent root of $\underline{T}$.

Williams (1952) showed the least squares estimate of θ_1^2 and $\underline{u}_{1i}$ were given by the first latent root and the corresponding latent vector of $\underline{S}$, where $\underline{S} = \underline{Y}\underline{Y}'$ and $\underline{Y}$ is as before, and that $\underline{v}'_{1j}$ was the first latent vector (again corresponding to θ_1^2) from $\underline{S} = \underline{Y}'\underline{Y}$.

Singular value decomposition of $\underline{Y}$ estimates β_i and I_j in one step.

8.3 Link between AUGFITCON and SVD.

Both the SVD approach and the AUGFITCON minimise the residual sum of squares (RSS) by the method of least squares. Consider an incomplete variety x centre table:

$$\hat{E}_{ij} = \hat{\mu}_i + \hat{\beta}_i \hat{I}_j$$

where E_{ij} is a missing entry in the table and $\hat{E}_{ij}$ is the estimated value from AUGFITCON. The RSS after fitting the AUGFITCON model to the table is:

$$RSS = \Sigma_{i^p}\Sigma_{j^p}(y_{ij} - \hat{\mu}_i - \hat{\beta}_i\hat{I}_j)^2 + \Sigma_{i^a}\Sigma_{j^a}(E_{ij} - \hat{\mu}_i - \hat{\beta}_i\hat{I}_j)^2$$

where i^p are those varieties present and j^p those environments at which the variety is present, the super-script 'a' denotes corresponding absence, $\Sigma_{i^p} + \Sigma_{i^a} = n$ and $\Sigma_{j^p} + \Sigma_{j^a} = p$.

The RSS will be minimised when the estimates for the missing values are such as to make:

$$\Sigma_{i^a}\Sigma_{j^a}(E_{ij} - \hat{E}_{ij})^2 = 0$$

since

$$\Sigma_{i^p}\Sigma_{j^p}(y_{ij} - \hat{\mu}_i - \hat{\beta}_i\hat{I}_j)^2$$

is fixed for a given data set and model.

The decomposition approach fits the model:

$$\underline{Y} = \lambda_1 \underline{P}_1 \underline{Q}_1' + \underline{\varepsilon}$$

$\underline{P}_1, \underline{Q}_1'$ are the corresponding first left and right latent vectors. $\underline{\varepsilon}$ is the error matrix. The residual sum of squares is given by:

$$\text{RSS} = \text{tr}(\underline{Y} - \hat{\lambda}_1 \hat{\underline{P}}_1 \hat{\underline{Q}}_1')(\underline{Y} - \hat{\lambda}_1 \hat{\underline{P}}_1 \hat{\underline{Q}}_1')'$$

$$= \sum_i \hat{\lambda}_i^2 \qquad \text{since } \lambda_1 = (\text{first latent root})^{\frac{1}{2}}$$

Since $\sum_i \lambda_i^2 = \text{tr}(\underline{Y}\underline{Y}')$ which is fixed, given the data, the RSS is minimised when λ_1 is the largest singular value.

The estimates for β_i and I_j from the two methods will only be equivalent when λ_1 is maximised. Since the estimates for the absent values minimise the RSS they must maximise λ_1. Thus the SVD approach, when used on tables completed by AUGFITCON estimates produces equivalent estimates for the variety sensitivities and environment effects as AUGFITCON.

When the data set is complete β_i and I_j may be calculated by finding the SVD of the data matrix.

Decomposition of $\underline{Y}$ = into

$$\underline{Y} = \lambda_1 \underline{u}_{i1} \underline{v}_{j1}' + \underline{\varepsilon}_{ij}$$

gives estimates for β_i and I_j.

λ_1 = $\sqrt{}$(the first latent root of $\underline{Y}'\underline{Y}$)

$\underline{u}_{1i}$ estimates β_i the variety sensitivity to changes in the environment

$\underline{v}'_{1j}$ estimates I_j the environment effect.

The remaining $\lambda_n \underline{u}_{ni} \underline{v}'_{nj}$, $n \neq 1$ constitute the error term $\underline{\varepsilon}$ in model (2).

8.4 Use of the SVD when the data are incomplete.

When the variety x centre table is incomplete only the regression approach may be used to estimate β_i and I_j . AUGFITCON produces estimates for absent values which may be used to complete the table. A SVD on the completed table produces identical estimates of β_i and I_j to those obtained from AUGFITCON analysis.

8.5 Application of SVD to a completed variety x environment table of yields.

A table with data on 15 varieties at 10 centres, but with 25 missing values, was used to demonstrate the results obtained from the two methods. The estimates of β_i and I_j from AUGFITCON and SVD on the completed table, in Table 32, are found to be identical apart from a scaling factor. Thus application of SVD on a completed data set gives equivalent estimates of interaction parameters as AUGFITCON on incomplete data sets. Although use of the SVD has no advantage over the regression model in the estimation of the β_i and I_j, since the regression model must be used to complete the table of yields, this example shows that multivariate techniques based on the

method of least squares can be applied to data sets completed by AUGFITCON estimates.

8.6 Extension of AUGFITCON.

The extension involves the addition of a second interaction term,

$$y_{ij} = \mu_i + \beta_i I_j + \gamma_i \xi_j + \varepsilon_{ij} \qquad (3)$$

where: y_{ij} is the yield of variety i at environment j

μ_i is the mean of variety i

β_i is the yield sensitivity parameter of variety i

I_j is the environment effect of site j

γ_i is a second measure of the sensitivity of variety i

ξ_j is a second measure of the environment effect of site j.

As in the AUGFITCON model the interaction terms in model (3) can be shown to be equivalent to the latent vectors corresponding to the first and second singular values from the SVD of $\underline{Y}$ when model (3) is fitted by the method of least squares.

Fitting model (3) by the method of least squares:

The method of least squares requires

$\sum_i \sum_j (y_{ij} - \mu_i - \beta_i I_j - \gamma_i \xi_j)^2$ to be minimised.

This leads to the standard Normal equations.

The side conditions are: $\Sigma I_j = 0$, as in AUGFITCON, and $\Sigma \xi_j = 0$,

In the case of an incomplete data set a term δ_{ij} must be introduced such that:

$\delta_{ij} = 1$ if y_{ij} is present in the data

and $\delta_{ij} = 0$ if y_{ij} is absent in the data.

The Normal equations would be as above but each term is multiplied by δ_{ij}. This modification adjusts the estimate of μ_i to allow for those varieties which do not appear in all environments:

$$\mu_i = \tilde{y}_i + (\beta_i \Sigma_{j^a} I_j + \gamma_i \Sigma_{j^a} \xi_j)/n_i$$

where $\tilde{y}_i$ is the mean of variety i at the n_i environments the variety appears, j^a are those environments at which the i^{th} variety was absent and n_i is the number of environments at which the i^{th} variety is present. (c.f. AUGFITCON where the adjustment to the mean was

$$\mu_i = \tilde{y}_i + (\beta_i \Sigma_{j^a} I_j)/n_i .$$

8.7 Link between Model (3) and the SVD.

Consider the model:

$$y_{ij} = \mu_i + \beta_i I_j \theta + \gamma_i \xi_j \omega + \varepsilon_{ij}$$

with the side conditions:

$$\Sigma_j I_j = \Sigma_j \xi_j = 0 \qquad \Sigma_j I_j^2 = \Sigma_j \xi_j^2 = \Sigma_i \beta_i^2 = \Sigma_i \gamma_i^2 = 1$$

$$\Sigma_j I_j \xi_j = \Sigma_i \beta_i \gamma_i = 0$$

The method of least squares requires:

$\sum_i \sum_j (y_{ij} - b_i - a_j c_i \theta - d_i e_j \gamma)^2$ to be minimised.

The Normal equations are:

$$\sum_j (y_{ij} - b_i - a_j c_i \theta - e_j d_i \gamma) = 0 \quad \text{(i)}$$

$$\theta \sum_i c_i (y_{ij} - b_i - a_j c_i \theta - e_j d_i \gamma) = 0 \quad \text{(ii)}$$

$$\sum_j a_j (y_{ij} - b_i - a_j c_i \theta - e_j d_i \gamma) = 0 \quad \text{(iii)}$$

$$\gamma \sum_i d_i (y_{ij} - b_i - a_j c_i \theta - e_j d_i \gamma) = 0 \quad \text{(iv)}$$

$$\sum_j e_j (y_{ij} - b_i - a_j c_i \theta - e_j d_i \gamma) = 0 \quad \text{(v)}$$

and lead to estimates of the form:

$$a_j \theta = \sum_i c_i (y_{ij} - b_i - e_j d_i \gamma)$$

$$= \sum_i c_i (y_{ij} - y_{i.})$$

$$\text{and } c_i \theta = \sum_j a_j (y_{ij} - e_j d_i \gamma)$$

$$\text{so } c_i \theta^2 = \sum_i \sum_j c_i (y_{ij} - y_{i.})(y_{ij})$$

$$\text{Likewise } d_i \gamma^2 = \sum_i \sum_j d_i (y_{ij} - y_{i.})(y_{ij})$$

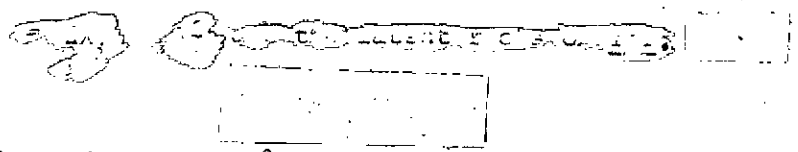
$$\text{If } t_{ik} = \sum_j (y_{ij} - y_{i.})(y_{kj} - y_{k.}) \text{ then}$$

$$c_i \theta^2 = \sum_j c_k t_{ik}$$

$$d_i \gamma^2 = \sum_j d_k t_{ik}$$

Hence θ^2 and γ^2 are latent roots of $\underline{T}$. The residual sum of squares (RSS) on fitting model (3) is given by:

$$RSS = tr(\underline{Y}'\underline{Y})$$



To minimise the RSS, $\Sigma\lambda_i^2$ must be minimised, hence since λ_1 and λ_2 are the largest λ_i then θ^2 and ω^2 must be the first two latent roots of $\underline{Y}'\underline{Y}$, that is, θ and ω are the first two singular values of $\underline{Y}$.

8.8 Calculation of the regression model(3).

When the regression model

$$y_{ij} = \mu_i + \beta_i I_j + \gamma_i \xi_j + \varepsilon_{ij}$$

is fitted to a complete data set

$$\beta_i \equiv u_{1i} \qquad I_j \equiv v_{1j}$$

$$\gamma_i \equiv u_{2i} \qquad \xi_j \equiv v_{2j}$$

where $\underline{u}_{1i}\underline{v}'_{1j}$ and $\underline{u}_{2i}\underline{v}'_{2j}$ are the left and right latent vectors of the first and second singular values from the decomposition of $\underline{Y}$.

The vector corresponding to the largest latent root gives the direction cosines of a line through the sample mean such that the sum of squares of the perpendicular distances from the points onto this line is a minimum. Once one line of this type is found a second line can be sought, at right angles to the first and corresponding to the second largest latent root and vector, which minimises the sum of squares of the perpendiculars onto the plane defined by the two lines (Gower, 1966), i.e. the latent vectors are independent of each other.

The calculation of the AUGFITCON regression uses available estimates for μ_i and β_i to regress the I_j against the y_{ij} to obtain estimates of I_j. A new estimate for μ_i is made and used to regress the β_i on the y_{ij} to obtain new estimates for the β_i. This approach can be used to fit model(3). The estimates of β_i, I_j are independent of γ_i, ξ_j so the estimates of β_i and I_j from AUGFITCON can be subtracted from y_{ij} and a modified joint regression analysis performed on $y_{ij} - \beta_i I_j$ to obtain estimates of μ_i, γ_i and ξ_j.

Hence to estimate γ_i and ξ_j :

(i) fit $\quad y_{ij} = \hat{\mu}_i + \hat{\beta}_i \hat{I}_j \quad$ by AUGFITCON,

(ii) determine $y_{ij} - \hat{\beta}_i \hat{I}_j = \hat{\mu}_i + \hat{\varepsilon}_{ij}$

(iii) fit $\quad y_{ij} - \hat{\beta}_i \hat{I}_j = \hat{\hat{\mu}}_i + \hat{\gamma}_i \hat{\xi}_j + \hat{\hat{\varepsilon}}_{ij}$

8.9 Incomplete data

When the variety x centre tables are incomplete model (3) must be applied to obtain estimates for the two interaction terms in order that a good representation of the data is possible. Completion of the data table with estimates from model (3) will result in the first two singular values from the SVD being maximised.

Because γ_i, ξ_j are smaller than β_i, I_j estimation of γ_i and ξ_j requires many iterations to ensure that accurate estimates are obtained.

8.10 Number of interaction terms required in model (3) - complete tables.

The ratio $\lambda_i^2/\Sigma\lambda_i^2$ gives the proportion of the variation explained by the inclusion of the i^{th} principal component (Mardia, Kent and Bibby (1979); thus it is possible to ascertain whether addition of extra terms in the AUGFITCON model would explain a sufficiently large proportion of the variation to warrant inclusion. The interaction term in the AUGFITCON model corresponds to the first principal component in model (2).

A SVD on a completed data set produces a λ_1 which dominates all other λ_i and which often accounts for over 80% of the variation. This result suggests that the inclusion of further terms in the AUGFITCON model will not bring about a sufficient increase in accuracy to be justified, λ_2 accounts for less than 10% of the variation.

8.11 Error in λ_i in complete data tables.

AUGFITCON estimates maximise λ_1 only, $\lambda_2 \cdots \lambda_n$ will not be maximised and so will be subject to error. The effect on λ_i of completing a variety x centre table, with AUGFITCON estimates was examined on a complete data set.

A complete 10 x 6 data set was chosen and six entries deleted. The latent roots estimated from the table completed with AUGFITCON estimates appear in Table 33. λ_1^2 (first latent root from the complete data set) dominates all other λ_i^2. The difference between λ_i^2 from the complete table and the $\hat{\lambda}_i^2$ from the completed tables are small. Although λ_1^2 is the only parameter maximised the difference in λ_i^2 and $\hat{\lambda}_i^2$ $i \neq 1$, is not large. This result indicates that $\hat{\lambda}_i^2$ is a reliable estimate of λ_i^2 when AUGFITCON estimates are used to complete incomplete tables, Table 33, at least when there are not many missing values.

8.12 Number of interaction terms required - incomplete tables.

Each incomplete table was completed with AUGFITCON estimates. The latent roots for each variety x centre table were calculated. The first latent root from each variety x centre table dominates all other roots. The proportion of the variation explained by each component appears in Table 34. The first principal component explains most of the variation, the minimum variation explained is 76%, in 1969. In general the first principal component explains 80-90% of the variation. The approximate 95% confidence intervals of the proportion of variance explained by the first principal component is approximately $\pm$2-3%, but in 1969, $\pm$6% and in 1978 $\pm$8% approximately. The second principal component on one occasion accounts for 9.5% of the variation, in 1969, but in general the second component accounts for about 7% and often less than 5% of the variation. Scree graphs (Cattell 1966) of the contribution of the principal components indicate that the first component completely

dominates all the others in every case, for instance Graphs 6 and 7.

8.13 To test the hypothesis that p-k latent roots of the data matrix are equal.

A matrix $\underline{A}$ has rank p with latent roots $\ell_1, \ell_2, \ell_3, \ldots \ell_p$. To test the hypothesis that the p-k remaining roots are equal let:

$$a_o = (\ell_{k+1} + \ell_{k+2} + \ell_{k+3} \ldots + \ell_p)/(p-k) \quad \text{and}$$

$$g_o = (\ell_{k+1} . \ell_{k+2} . \ell_{k+3} . \ldots \ell_p)^{-(p-k)},$$

then $(n-\{2p + 11\}/\{p-k\})(p-k)\log_e\left(\frac{a_o}{g_o}\right) \sim \chi_{(p-k+2)(p-k-1)}^{\frac{1}{2}}$

where n is the number of varieties, (Mardia, Kent and Bibby (1979)).

This test was applied to a 15 x 10 data set and the completed data tables for each year. In each case the test was performed for k=1, i.e. all the latent roots other than the first can be considered to be equal. For each variety x centre table this hypothesis was not rejected at the 5% level. When the test was applied for k=0, i.e. all the terms must be included, this hypothesis was rejected at the 5% level for all the tables except the 1969 table, where the significance level was about 7%.

This result suggests that in almost all the years considered the model with one interaction term is sufficient to explain most of the variation, i.e. a model of the form of AUGFITCON is adequate.

A note on the test.

A test of the remaining p-k roots being equal will always be rejected if the last root is zero. Thus when this test was applied only the roots which accounted for 1% or more of the variation were considered.

CHAPTER 9

Use of the Biplot.

9.1 Introduction

The biplot is a graphical display of matrices which utilises the singular value decomposition and can be used to find the type of model to fit the data. The biplot has been described by Bradu and Gabriel (1978).

Application of this technique can show whether a general additive model fits the data or whether only a subset of the data is fitted by the model. A low goodness of fit value of the biplot shows that the data are not suitable for a two-way analysis.

The biplot displays the rank 2 approximation of the data matrix by plotting column and row markers. If only the markers of the rows are co-linear then a 'rows' regression is applicable, i.e. a model of the form:

$$y_{ij} = \mu + \alpha a_i + \beta b_j + \gamma a_i c_j$$

If only the markers of the columns are co-linear then a 'columns' regression is applicable, i.e. a model of the form:

$$y_{ij} = \mu + \alpha a_i + \beta b_j + \delta d_i b_j$$

If both the columns and rows markers are co-linear then a concurrent model is applicable, i.e. a model of the form:

$$y_{ij} = \mu + \alpha a_i + \beta b_j + \lambda a_i b_j$$

Application of the biplot approach may help to illustrate the form of the interaction present in the data sets, whether the interaction

arises from the rows, columns, or both.

9.2 Method.

Application of the biplot technique to the table of variety x region (adjusted) mean yields, Table 35, produces Graph 8.

9.3 Results

The goodness of fit is high, 92%, which suggests a two-way analysis is applicable to this data set. (See chapter 8 for a test for the number of principal components that should be included.) The variety and region markers in the biplot are seen to be almost co-linear, with the exception of WC. The lines of variety and region markers do not intersect at rightangles which shows interaction between varieties and regions.

From the analysis in Chapter 6 the marker for Estima, code ET in Graph 8, could be expected to be detached from the remainder of the varieties, since Estima has many outlying values. However, Estima's marker lies with the other varieties and WC is detached from the rest of the regions. This result suggests that the interaction of Estima is due to the variability of WC rather than Estima.

Replacement of Estima's observed yield at WC by its estimated value produces little affect on the position of the markers for either Estima or WC, Graph 9. This new analysis places Estima firmly with the other varieties and the unaffected position of WC

indicates that WC is a genuinely variable region.

9.4 Discussion

The sites in WC: Harper Adams, Myerscough, Rosemaund and Lancashire all exhibit coefficients of variation (CV) higher than other sites, Table 21. The CVs in EC are comparable to the values from WC sites. This can be explained by the low yields in EC inflating the CV values. Since WC sites have higher mean yields than EC the trials in WC must have higher variances associated with them to cause high CV values. In Table 4 WC trials give much higher residual mean squares than EC trials. Thus the variability of WC can be traced back to variable trials.

9.5 Application of Biplot to examine national effects.

A biplot was made of data concerning 14 varieties appearing in England and Scotland during 1971-1978. The variety regional mean yields for Scottish regions are based on data from 1971-1978 and for English regions on data from 1969-1978.

9.6 Results

The biplot from English and Scottish regional data, Graph 10, is different from the pattern of variety and region markers in Graph 8. The biplot fit is lower, 83%, cf 92% for English regions only, but still high enough for a two-way analysis. Although there is a co-linear pattern between region and variety markers, there is a

large amount of scatter along these lines. The markers for WC and SW lie away from those for regions. The markers of Drayton, code DY in Graph 10, Strath, code ST, and Stormont Enterprise, code SE, increase the scatter of the markers about the general line.

As can be seen from Table 36, Drayton yields particularly poorly at NS. The effect of this value of Drayton on the biplot is seen when this observation is replaced by its fitted value, Graph 11. The NS marker moves towards the other region markers and the marker for Drayton lines up with the other variety markers.

9.7 Discussion.

From Table 4 SW sites are not particularly variable although these sites give higher yields than most regions. SW's large regional effect is responsible for pushing the SW marker away from the other region markers. NS has the lowest environment effect, so placing it at the opposite end of the line of region markers. Although NS and Drayton display considerable interaction NS is not a highly variable region. Replacement of Drayton's observation by its fitted value reduces the scatter of points about the line, Graph 11. The fact that the NS marker moves into line with the other region markers shows that NS is not a region which displays generally high variation and that its former position was due to interaction with Drayton.

The new alignment of the region markers suggests that either SW or WC are outlying, compared to other regions. SW has yields close

to those of WC but displays less variation.

From the modified biplot, arising from the data set with the value of Drayton at NS replaced, most English and Scottish regions can be considered to lie on the same line, only SW lies at a distance from the line. Thus, no one set of parameters can sucessfully combine all regions in an additive or 'regression' model, and several possibilities exist in combining regions, e.g. SW, NC, EE, NS and WC, ES, WS say. Scottish regions do not lie on a line that is very different from most English regions which indicates that effects of region from both countries do not come from very different populations.

CHAPTER 10

Mean variety yields as percentages.

10.1 Introduction

Examination of mean yields may show varietal differences due to environments. Since our data are incomplete the mean yield for those varieties which do not appear at all sites must be adjusted, see chapter 6. Expressing the mean yields as a percentage of a control variety's yield shows how variety yields compare to the control's yield.

10.2 Method.

In Table 37 the adjusted mean yields at each eastern and western region during 1971-1977 are expressed as percentages of the mean yield of Pentland Crown, which is defined to yield 100% at each region. Pentland Crown is used as the standard since it is a common control against which yields of new varieties are compared.

10.3 Results.

Pentland Crown is generally the highest yielding variety, in many environments it is not out-yielded. In other environments Pentland Crown is out-yielded by many varieties, notably in SW72, SW71, and EE71. (EE71 stands for East of England in 1971 etc.) The range of the yield of Pentland Crown is large, from 34t/ha at EE76 to 62t/ha

in WC74.

10.4 Discussion - Table 37

Pentland Crown is reputed to have a high resistance to drought (NIAB Farmer's Leaflet No.3) and to have a yield fairly insensitive to differences in environment (Simmonds, 1980). If this is so then the following pattern could be expected in a table such as Table 37,

(i) Pentland Crown should not in general be out-yielded,

(ii) Pentland Crown should rarely be out-yielded under drought conditions,

(iii) the yield advantage of Pentland Crown should be least in wet environments.

In Table 37 environments have been ordered by the amount of rainfall (cms.) received during the growing season.

There is no clear pattern between rainfall and the performance of Pentland Crown. e.g. At EE76 Pentland Crown yields 34t/ha, and five varieties out-yield this value, the lowest yield is 95% of Pentland Crown's. At SW76 Pentland Crown yields 51t/ha and no variety out-yields this value, the next highest yielding variety yields 86% of Pentland Crown's yield. Both EE76 and SW76 receive the same low rainfall, 9.5cms.

The suggestion that these contrasting results arise from differences in distribution of rainfall at sites is not necessarily true. The distribution of rainfall in EE76 and SW76 is very similar, with very low rainfall in April and June, under 1.0cms, and

low rainfall in the other months, Table 38. This example illustrates the considerable variation that can arise from one region to another under similar conditions in terms of rainfall, and so complicate interpretion of the figures.

Table 37 shows that there is no simple relationship between total yield and total rainfall during the growing season.

10.5 Use of aggregated data.

The conflicting results in Table 37 may be due to 'noise' exhibited in the data, uncontrollable variation, and in order to remove the effect of this variation it is neceassary to aggregate the data and look at yields over years, or over regions.

The yields of the varieties at English regions were calculated, Table 35. Data were also aggregated to examine the mean yields of varieties on three soil types: clay, sand and loam, Table 39.

10.6 Results.

In Table 39 Pentland Crown is rarely out-yielded by any other variety and never consistently out-yielded by any variety, except Paragon. In eastern regions Pentland Crown is out-yielded once. There is a larger difference in the mean yield of Pentland Crown and the mean yield of all varieties in eastern regions than in western regions.

When sites are split by region 19 varieties have mean yields that vary by 10% or more of Pentland Crown's yield. This result indicates that these varieties are favoured by some regions more than others, relative to Pentland Crown. Only one variety displays a similar variability when the sites are split by soil type. The partition of the sites by soil type does not involve all sites, see Table 9 for the composition of regions and soil groups.

10.7 Discussion - Table 39

Pentland Crown is only out-yielded once in eastern regions, which are (generally) the drier regions (average rainfall: EE, 21cms, EC, 24cms), six times in the wetter western regions (average rainfall: SW, 29cms, WC, 36cms) and four times in NC (average rainfall: 33cms).

This agrees with the expected behaviour of Pentland Crown expressed in 10.4 above. In environments with low rainfall Pentland Crown is rarely out-yielded. This result enforces the idea that this variety yields well under drought conditions, and that when water is not a limiting factor other varieties can out-yield Pentland Crown. At eastern sites Pentland Crown out-yields the mean yield of all varieties by 5t/ha, but at western sites this difference is reduced to 2t/ha.

The yield of Pentland Crown over regions varies by about 5t/ha, which is less than for other varieties, this indicates that Pentland Crown gives more consistent yields than other varieties. Varieties

marked + in Table 39 are those that can be considered to interact with environments to a greater extent than Pentland Crown's yield since their percentage yields vary by 10% or more. For example, S6247/1 yields 102% in WC and 86% in EE of Pentland Crown's yield. The varieties which come into this class include, Ulster Brevet, Drayton, Pentland Hawk, Pentland Ivory and Record.

The partition of sites by soil type produces only one variety that has percentage yields of Pentland Crown that vary by 10%, S6247/1. This result indicates that all varieties interact with soil type in a similar way.

No simple linear relationship between total yield and rainfall for April-August was found. This conflicts with McDermott and Ivinns (1955) who suggested a linear relationship between rainfall and yield. Their relationship was between total yield of Majestic and May-September rainfall for from eight year's data. From our data a poor linear relationship exists between rainfall in the growing season (April - August) and total yield for most varieties. A better linear relationship is found between total yield and rainfall for May-September for many varieties, however in the case of Majestic the linear relationship is not as close as found by McDermott and Ivinns (1955).

10.8 Variety x year data

Analysis of the variety mean yields for each year, Table 41, attempts to overcome the effects of 'noise' in Table 37. The (adjusted) mean yield of a variety for each year, in which the variety was grown at five or more sites is given.

The mean variety yields are expressed as a percentage of the mean yield of Pentland Crown, defined to yield 100%. Since Pentland Crown does not appear in 1969 this year's data are omitted.

10.9 Results

In 1970 several varieties (4) manage to out-yield Pentland Crown, but in other years few achieve this, Table 40.

Only Cara, Désirée, Stormont Enterprise and DHS/21 produce yields approaching Pentland Crown's yield in 1976, a severe drought year, all other varieties yield considerably less than Pentland Crown.

Eleven varieties give yields that vary by 10% or more of Pentland Crown's yield, which indicate that they interact more with the years relative to Pentland Crown than other varieties. Eight of these eleven varieties produce their relatively lowest yields in 1976, this indicates they are less drought resistant than Pentland Crown.

10.10 Discussion.

There is a strong relationship between rainfall during the growing season and the number of varieties equalling or out-yielding Pentland Crown's yield. In years of low rainfall (1976, 94cms.) no variety out-yielded Pentland Crown, but in years of high rainfall (1973, 174cms.) several varieties out-yield Pentland Crown. These results agree with the assertion that Pentland Crown is a drought resistant variety. From Table 40 it would appear that Pentland Crown's drought resistance is higher than that of the other varieties. The rare occasions on which Pentland Crown is out-yielded testifies to Pentland Crown's ability to produce a consistently high yield over a range of years. Again there is no simple relationship between variety mean yield and rainfall during the growing season.

CHAPTER 11

Analysis of mean yields by an additive model.

11.1 Introduction

Use of an additive model which removes effects of year/region and variety can help to identify from where the interaction stems.

11.2 Variety x year data.

An additive model of the form:

$$y_{ij} = m + v_i + s_j + e_{ij} \quad ,$$

where y_{ij} is the yield of variety i at environment j ,

m is a general mean ,

v_i effect of variety i ,

s_j effect of year j ,

e_{ij} an error term,

was fitted to the table of variety x year (adjusted) mean yields, Table 41.

11.3 Results

Fitting the model to Table 41 suggests Estima and 1973 interact considerably, Graph 12. The test of John and Prescott (1975) agrees with this, indicating this point to be outlying.

The residual mean square (RMS) which arises from fitting this model is about 100 times greater than the plot error variance. This result shows that there is considerable interaction in Table 41. A large amount of interaction exists even after the value of Estima in 1973 has been accounted for.

11.4 Discussion.

No particular year is responsible for a large proportion of the residual sum of squares (RSS) in Table 42 . 1973, a high yielding year and 1976 a low yielding year, give the highest and second highest RSS values respectively. The large RSS from 1973 is due to Estima rather than 1973 being a particularly variable year; on deletion of Estima's value the RSS for 1973 becomes similar to that of other years. The extraordinary yields of Estima in 1973 can be gauged by comparison of its yield with those of Pentland Crown. Estima yields about 20t/ha more than Pentland Crown in 1973 but in other years is out-yielded by Pentland Crown, Table 43.

11.5 Variety x region data

Analysis of adjusted mean yields at English regions, Table 35, indicates that there is a significant difference between variety yields recorded at different regions. A plot of residuals against the quantiles of the standard Normal distribution (QSND), Graph 13 show that Estima interacts with WC to a considerable extent. No other variety's yield appears to interact with a region to such a

degree. A model of the form:

$$y_{ij} = m + v_i + r_j + e_{ij} \quad ,$$

where y_{ij} is the yield of variety i at environment j ,

m a general mean ,

v_i effect of variety i ,

r_j effect of region j ,

e_{ij} an error term,

when applied to these data produces a residual mean square (RMS) about triple that of the plot error variance. This high RMS value compared to the plot error variance indicates that there is considerable variety x region interaction.

11.6 Discussion

Examination of the residuals from the fitted model can help to indicate the way in which varieties respond to regions, Table 44. Pentland Crown has negative residuals at wetter regions and positive residuals at the drier regions. A similar pattern of residuals is found for Désirée, another drought resistant variety (NIAB, 1977). Record, has positive residuals at wetter regions, but its yield is not affected much by any particular region. Pentland Crown and Cara have positive residuals at EC. Pentland Crown has negative residuals at SW, a wet region. Désirée's yield exhibits little interaction with any region.

The WC and SW regions are the most variable regions. WC has a RSS twice as large as that for either eastern region. The varieties whose yields interact most with the WC sites are: Clada, Estima, Gracia and Strath. Estima and Gracia interact considerably with SW.

CHAPTER 12

A comparison between English and Scottish regional results.

12.1 Introduction

Potato trials are performed at three regions in Scotland, East of Scotland, ES, West of Scotland, WS, and North of Scotland, NS, with usually two trials in each region. Scottish trials are grown since results from English trials are unlikely to be applicable to Scotland due to the many climatic differences etc. between the countries.

The extent of Scottish trial data is limited compared to English data, both in the number of trials and the number of varieties tested. Data, from the Scottish Colleges' trials, for 1971-1978 on 14 varieties (common to the English trials) were considered from six sites.

12.2 Method.

The mean yield of Pentland Crown at each region over ten years was defined to yield 100% and the yields of the other varieties were expressed as a percentage of Pentland Crown's yield, Table 45.

A simple additive model of variety and regional effects was applied to the adjusted mean yields to indicate any interaction present in the table.

12.3 Results

The number of times Pentland Crown is outyielded or equalled in Table 45 indicates the presence of a substantial regional interaction, the number at each region is: EC, EE, NC none; SW, 1; ES, 2; WC, 3; NS, 4 and WS, 8. Thus the table shows that Pentland Crown gives the highest yields (generally) in most English regions but not in Scotland, particularly WS.

Analysis of variety x region mean yields, Table 36, indicates that there is a high interaction between variety yield and region. Use of the mean yields over a period of years is aimed to remove some of the very high variation of the type displayed in Table 37. The interaction of variety yields and regions in Table 36 is about four times larger than the interaction measured in a similar analysis of only English regions.

Drayton, Estima and Strath are found to have the largest residual mean squares (RMS). NS and WS are similarly highlighted as having large RMS values compared to other regions. High RMS values indicate regions that are more variable in their effect on yield than the other regions. EE, EC and NC have RMS values much less that of NS and WS which indicate that these former regions are considerably less variable than the latter regions, Table 46.

Drayton's yield at NS is highlighted from the plot of ordered residuals against quantiles of the standard Normal distribution (QSND) as being an outlying observation. This hypothesis

is confirmed by a test of John and Prescott (1975). When this observation is replaced by its estimated value only the yields of Estima and Strath still have relatively large residuals but the RMS are considerably less than the original RMS from Drayton. The high RMS of Strath and Estima are due to several large residuals. This suggests that these varieties are genuinely interacting with regions to a greater extent than other varieties.

The RMS due to NS falls considerably, when the yield of Drayton is replaced by its estimated value, and becomes similar to the RMS value of WC. This result suggests that NS is not generally a variable region and that its formerly high RMS value was due to interaction with Drayton. After replacement of Drayton's NC yield, WS still has a high RMS value which cannot be attributed to any specific varieties. This suggests, perhaps, that WS is a variable region and more variable than any other.

In the corresponding analysis concerned with only English regions WC was found to be the most variable region. When Scottish regions are included WS and ES are found to be more variable than WC. NS has a RMS less than WC, but higher than the RMS of most English regions, Table 46.

12.4 Discussion

This analysis highlights the interaction of Drayton's yield with NS and suggests considerable interaction of the yields of Estima and Strath with region. The analysis also indicates more interaction

between variety yields with Scottish regions than English regions. Only SW and WC exhibit variation approaching the Scottish regions'.

The yields of Désirée and Croft exhibit least interaction with the regions which suggests that these are 'safe' varieties to use in any region. Estima's yield interacts more favourably with Scottish rather than English regions; Strath's yield interacts unfavourably, at ES and WS, but favourably at NS. Pentland Crown's yield only interacts most with WS (the lower yield may be partly explained by Pentland Crown being affected by disease in 1972 in this region) but little more than in English regions at ES and NS. Only Croft interacts less in Scottish regions than English regions.

CHAPTER 13

Correlations between environments and between varieties.

13.1 Introduction

If the correlation of yields from a pair of sites is high then each site is producing similar information about variety performance. In cases of high correlation between site yields one site of the pair could be discarded without much loss of information on the way varieties perform. If yields at sites are poorly correlated then each site is contributing different information about variety interaction with environment, i.e. each site gives a different relationship between variety yields. In cases of low correlation omission of a site would reduce the amount of information contributing to the overall picture of the varieties' performance.

Correlations between variety yields can be useful to indicate the behaviour of a variety in comparison to other varieties. For example, if a variety does not interact with environments to the same extent as other varieties with which it is grown, this variety will have low correlations with varieties. If, however, a variety reacts to environments in a similar manner to another variety, then the varieties will be highly correlated. Varieties with sensitivites not close to 1.00 can be expected to be poorly correlated with varieties of average sensitivity, within the context of these data.

Our data sets are incomplete and complete correlation matrices cannot be simply calculated.

13.2 Effect of missing values on the correlation coefficient.

The correlation between X and Y is given by:

$$\rho = \frac{Cov(X,Y)}{\sigma_X \sigma_Y} = \frac{\Sigma(x-\bar{x})(y-\bar{y})}{(\Sigma(x-\bar{x})^2 \Sigma(y-\bar{y})^2)^{\frac{1}{2}}}$$

which can only be completely determined when both X and Y are present at all sites in the data table. From our data sets it is not possible to calculate a correlation coefficient between all pairs of X and Y over all environments.

To overcome this difficulty the missing values in the data set may be estimated by the method of FITCON or AUGFITCON, see chapter 6. The complete correlation matrix between centres and between varieties can then be calculated.

13.3 Effect of estimated values in the correlation matrix.

If the data set is completed by FITCON estimates the correlation will, in general, be over-estimated. The effect of over-estimation will be large if the number of missing values is high. Missing values are replaced by an estimate of the form,

$y_{ij} = v_i + I_j$ if FITCON is used.

where v_i is the effect of variety i

and I_j is the effect of environment j.

For any pair of varieties the difference Y - X, between FITCON estimates, will be a constant. At sites where both X and Y are absent,

$X = Y + k$ so

$$\rho = \frac{\Sigma(y + k - (\bar{y} + k)(y - \bar{y})}{(\Sigma(y + k - (\bar{y} + k))^2 \Sigma(y - \bar{y})^2)^{\frac{1}{2}}}$$

thus, the varieties will be perfectly correlated.

If AUGFITCON is used, missing values are estimated by:

$$y_{ij} = v_i + \beta_i I_j$$

where v_i and I_j are as in the FITCON model above and β_i is the variety sensitivity parameter.

At a site where both X and Y are absent differences between missing values are given by:

$$\begin{aligned} x - y &= v_x - v_y + \beta_x I_j - \beta_y I_j \\ &= v_x - v_y + I_j(\beta_x - \beta_y) \\ &\equiv K_1 + I_j K_2 \end{aligned}$$

where K_1 and K_2 are constants for any pair of varieties. Since the difference between X and Y depends only on an environment variable at sites where X and Y are both absent, the two varieties will be perfectly correlated.

So, if AUGFITCON estimates are used to complete an incomplete data table, the resultant correlations are likely to be over-estimated. If the number of missing entries in the data table

is small, the correlations from a completed data set could give a useful indication of association since there will be few occasions of perfect correlation between varieties, and this should not distort the correlation matrix calculated compared to the 'actual' associations from observed values.

13.4 Example of the effect of AUGFITCON estimates on the correlation matrix.

The effect of AUGFITCON estimates on the correlation matrix was examined by use of 1975 data.

A correlation matrix was calculated from a complete data set on 15 varieties at 9 centres in 1975. These correlations represent the 'real' associations between variety and centre, Tables 47 and 49. The entire, but incomplete, data from 1975 involves 20 varieties at 19 centres. The missing values in this data set were replaced by their AUGFITCON estimates and the complete correlation matrices computed. The correlation coefficients, for varieties and sites used in the first analysis, are given in Tables 48 and 49.

Comparison of the correlation matrices shows that in the completed data set correlations are consistently higher than correlations arising from the 'real' data. Correlations between varieties from the complete data have a similar range compared to those from the completed data, but a lower average correlation. Correlations from the completed data are more contrasted than from the complete data, high correlations become higher and low

correlations become lower. When considering centres the range of correlations -0.26 - +0.77, contrast with 0.07 - 0.74, from the complete and completed tables. In the centre x centre yield correlation matrix there are eight negative correlations which all become smothered by the tendency of AUGFITCON estimates to increase correlations.

13.5 Calculation of correlation coefficients.

To obtain an indication of the size of yield correlations the data for each year were split to obtain the largest possible complete data matrices. Correlations from these data sets were then determined. Often only a proportion of the sites can be included in the data matrix for a given selection of varieties, so two data sets may arise from the same year. In this way many yield correlations are estimated. Clearly, not all yield correlations are possible, unless each correlation is computed individually. This division of data enables a large number of correlations to be obtained which indicate the general magnitude of yield association.

13.6 Results.

All correlations between sites in excess of 0.75 were investigated to discover whether high correlations occur only once, or if yields of pairs of sites are often highly correlated, Table 50.

1973 and 1976 yield a large number of high (greater than 0.75)

correlations, 1977 and 1972 a substantially smaller number and the remaining years very few. Cambridge, produces the largest number of high yield correlations with other sites; Sutton Bonnington gives rise to a number of high correlations.

The sites with which Cambridge and Sutton Bonnington produce several high yield correlations were examined.

(i) Correlations with Cambridge.

Morley, Seale Hayne, Sutton Bonnington and East Riding 'A' all produce two or more high yield correlations with Cambridge in the initial analysis. The coefficients for each year between Cambridge and these four sites were calculated, Table 51. Each of the sites, except Morley, give positive and negative correlations, five or more of which are 0.5 or less. Thus Cambridge's yield displays high correlations with these sites but they are inconsistent over years.

(ii) Correlations with Sutton Bonnington.

Morley, Myerscough, Rosemaund and North Riding all produce three or more high yield correlations with Sutton Bonnington. However even Morley, with which Sutton Bonnington has 4 correlations greater than 0.76 produces very inconsistent correlations over years, 0.87, in 1977 and -0.59 in 1975. The other sites also produce a wide range of yield correlations with Sutton Bonnington, Table 50.

Correlations between varieties are generally high and fairly consistent each year. In particular variety groups one variety's yields can be identified as being consistently less well correlated with the other varieties. This can be explained by a variety having a particularly high or low yield sensitivity, Table 52. Cara

is poorly correlated to other varieties and this is due to Cara having a yield sensitivity below 1.00 .

13.7 Discussion

Both Cambridge and Sutton Bonnington show that although in any one year a pair of sites may have a high yield correlation, (e.g. 1973, Table 50) in another year the same pair of sites may have low correlations (e.g. 1972, Table 50). Since the level of correlation between sites is dependent upon the year, it is not possible to forecast which pairs of sites will have high yield correlations in advance of planting.

Hence the omission of any of the currently used sites will result in a loss of information about variety performance since the low yield correlations between sites show that each site is contributing different information on variety performance.

The largest number of high yield correlations between sites occur in 1976 and 1973. These are respectively the driest (and very low yielding) and wettest (and high yielding) years. This result suggests that in a drought year sites give uniformly low yields, thus making many site yields well correlated, but in a wet year sites give uniformly high yields, again causing high correlations between yields at sites. Thus under extremes of rainfall a large number of high yield correlations occur, whereas in more 'average' years site yields are generally uncorrelated.

13.8 Correlations from mean yields over years at English regions.

Complete yield correlation matrices can be obtained from Table 35, the table of mean yields at each of the English regions.

Variety yields which are poorly correlated with each other are those which interact more with region compared to varieties which exhibit little unexpected interaction, (average sensitivity). Thus varieties with a large number of low correlations are those which display the greater variety x region interaction.

The range of correlations arising from Table 35 is from 0.22 - 1.00 . The correlations are generally high with 70% of the variety x variety correlations greater than or equal to 0.75%. Over a third of the entries in the correlation matrix less than 0.75 are due to six varieties, namely: Cara, Estima, Gracia, Paragon, 6247/1 and 916/4.

Cara has sensitivity parameters consistently below 1.00 and three significantly different from 1.00; Estima, Gracia, Paragon, S62471 have $\hat{\beta}_i$ parameters above 1.00 and all these varieties have at least one $\hat{\beta}_i$ significantly above 1.00. These estimates of β_i combined with the large number of low yield correlations with other varieties indicate that these varieties interact differently with the regions compared to other varieties. In 1976 and 1977 916/4 has β_i estimated at about 1.00, but in 1978 β_i is estimated below 1.00 but not significantly lower. There is no clear reason why this variety

should be grouped with these other varieties.

13.9 Correlations from yields at English and Scottish regions.

Another complete correlation matrix can be obtained from Table 36, the table of variety mean yields at English and Scottish regions. The range of variety yield correlations is wide, from 0.06-0.96, but correlations are generally lower than in the correlation matrix from the English regions. Over half of the correlations are under 0.75. The two varieties which have most low yield correlations are Strath and Estima. Both have a high residual sum of squares when the additive model is fitted to this data set, which indicates interaction with region. Drayton, Maris Piper, Paragon and Pentland Crown also have low yield correlations in 9 of the 13 variety pairs.

The lower yield correlations between varieties in Scottish regions compared to English regions illustrate considerable differences between the way varieties interact with regions from the two countries, (e.g. correlation between Pentland Crown and Pentland Squire's yield: over all regions, 0.61, over English regions only, 0.93). The lower yield correlations with Scottish regions indicates that variety behaviour is more variable in Scotland than England.

13.10 Region x Region yield correlations, England.

Table 35 can be used to obtain a complete region x region yield correlation matrix for English regions. The correlation matrix is given in Table 53. The lowest correlation is between NC and SW and the highest between EE and EC. SW has generally poor yield correlations with regions, EE excepted.

13.11 Region x Region yield correlations, England and Scotland.

The correlation matrix, of yields between all regions appears in Table 54. (The effect of using a different group of varieties is illustrated by the change in the correlations between pairs of English regions from the correlations in Table 53.)

SW region's yields are least well correlated with other English regions. The range of yield correlations between English regions is 0.47 (SW and NC) to 0.89 (EE and EC).

The correlations between yields at Scottish regions are much smaller, compared to English regions, the range being 0.38 (NS and ES) to 0.52 (NS and WS). Thus Scottish regions give more contrasted results than English regions.

Correlations of yields between English and Scottish regions produce generally lower values than between pairs of English regions but higher values than between pairs of Scottish regions. ES and WC

yields have the highest correlated results (0.83) but SW has low yield correlations with all Scottish regions.

These correlations, although generally higher than the correlations of yields between sites within years, are still low and illustrate the different results obtained from English and Scottish trials.

Low correlations of yields between pairs of Scottish regions show that each region contributes important information about variety x region interaction. The higher yield correlations between pairs of English regions show that the yields from the regions are (apart from SW) more similar than those from Scotland.

CHAPTER 14

Recommended Varieties.

14.1 Introduction

The Recommended List is divided into four classes:

G General use,

S Special use,

P Provisional recommendation, for a variety on which further trials are still in progress,

O becoming Outclassed.

No variety is recommended on less than three years trials (Richardson, 1979). The recommended varieties (Table 55) include King Edward, Maris Piper, Record etc. One would expect varieties recommended for general use to yield well over all environments. Croft, Désirée, Estima and Maris Piper all yield a minimum of 90% with most varieties yielding 95% or more of Pentland Crown's yield, Table 56. This result would suggest these varieties give generally high yields.

King Edward, Pentland Dell and Pentland Ivory yield somewhat less than 90% of Pentland Crown's yield. Their yield is less consistent across regions than the previous group of varieties. This result may suggest that this latter group is less stable compared to Pentland Crown. (This is, however, not in agreement with the sensitivity parameters.) Both Pentland Ivory and Pentland Dell

yield rather poorly in the EC (East Central) region, almost the same yield as Record, better than Record in EE (East of England) region and about the same yield in SW (South West) region. This would indicate that unless Pentland Dell and Pentland Ivory are grown to exploit a specific character, they should not be grown in preference to Désirée, for instance, to obtain high yields.

A 'S' recommendation is awarded for some specific trait of the variety other than yield (usually). However, a variety with a 'S' recommendataion ought to yield fairly well and consistently over a range of environments, unless it is only recommended for certain areas. Record is recommended because of its processing quality. Although Record yields under 85% of Pentland Crown's yield, its yielding ability is quite consistent over all regions and soils. Majestic, recommended for its long term storage, yields over 90% of the control yield at all site groups.

Almost all recommended varieties yield more at western sites than at eastern sites, but the difference between eastern and western sites is less for non-recommended varieties. It is, however, difficult to establish if this difference is significant. Pentland Crown does not perform that much better at SW sites compared to other varieties as it does at other regions. (Mean yield for Pentland Crown 51.6 t/ha, all other varieties 49.6 t/ha, the nearest the two values approach each other.) For this reason SW appears to be more favourable for most varieties than it may really be, since this advantage is measured relative to Pentland Crown. However, many varieties did record their highest yields in this region. This

result may be due to SW having adequate rainfall (usually) and so eliminating differences between drought resistant and drought susceptible varieties.

14.2 Importance of yield potential.

The importance of the yield character in determining whether a variety appears in the recommended list can be see from Table 57. Only five recommended varieties appear in the twelve highest varieties over regions and only four recommended varieties appear in the eleven highest yielding varieties over soil type. In the two groups of environments, soil types and regions, about half of the recommended varieties appear in the top ten yielding varieties.

This result would suggest that the yielding ability of a variety is important but not given as much importance when recommending varieties as may be first thought. Although recommended varieties have good yielding ability (in general), with half of them appearing in the top third of varieties considered, they cannot (in general) be considered the highest yielding varieties.

14.3 Variance components arising from Recommended and non-Recommended varieties.

If the recommended varieties are chosen for the way they interact with environment, analysis of recommended varieties may produce different variance components from non-recommended varieties. As the number of recommended varieties is small all varieties which

appear on the recommended list during 1969-1978 were analysed together. The remaining varieties are regarded as non-recommended varieties.

14.4 Analysis

A similar analysis was performed as on the whole data set in chapter 5. The variance components were estimated for both variety groups with the data partitioned into NIAB and ADAS centres.

14.5 Results

Results from the analyses appear in Table 58. Again, as in the complete analysis, the standard errors are large which does not permit a very useful interpretation of the variances. The estimated variance for each data set follows the same pattern as for the entire data set; although the σ^2_{VY} component for recommended varieties is greater than for non-recommended varieties the difference is not large.

14.6 Discussion

The variance estimates only suggest that there may be differences in the effect of years and centres on recommended and non-recommended varieties. Thus the analyses indicate that recommended varieties cannot be considered affected by year or centre effects any differently compared to non-recommended varieties.

CHAPTER 15

Variety Pedigree.

15.1 Introduction

For some varieties in our data it is possible to obtain parentages and so identify related varieties. Many varieties have unknown parentages, so only a few varieties are considered.

The parents of Cara, Clada, Désirée, Estima, King Edward, Maris Piper, Paragon, Patrones, Record, Stormont Enterprise and Ulster Lancer were obtained from NIAB (1977). Ulster Lancer has King Edward as a parent and Patrones has Record as a grand parent. Apart from these associations, parents of varieties listed above are varieties not featured in the data. Hence it is not possible to attempt to group the varieties by family to discover family traits.

15.2 Some variety relations.

Pentland Dell and Pentland Raven are related through Craigs Defiance.

Pentland Dell is a parent to Croft.

Pentland Hawk and Pentland Dell have Roslin Sasumua as a parent.

Pentland Ivory and Pentland Squire are siblings of Pentland Crown and Pentland Dell.

King Edward and Maris Piper are parents to Drayton. (NIAB 1977 and Holden 1977).

15.3 Connections between related varieties.

In the family connections above siblings could be expected to be related to their parents in their interactions with environment and in their yielding ability.

Variety yields tend to be highly correlated, both over years and within years, Table 47, so to find Pentland Squire and Pentland Ivory with a high yield correlation is not necessarily due to their sibling connection. (Correlations given below refer to those computed from mean yields, Table 35.) Pentland Squire consistently out-yields Pentland Ivory and this helps to explain their correlation of 0.82 . Neither Pentland Squire or Pentland Ivory out-yield Pentland Crown and the yield of Pentland Squire is generally 2-4t/ha less than Pentland Crown, except at WC. The large difference between the yields of these two varieties at WC is responsible for producing a correlation of -0.04, the yield correlation from the other regions is 0.91. Pentland Squire is never out-yielded by Pentland Dell and their yield correlation is 0.78. Pentland Ivory only once equals Pentland Dell's yield at the regions but Pentland Ivory generally yields slightly less over each region, the correlation between these varieties' yields is 0.99. The correlation between the yields of Pentland Ivory and Pentland Crown is 0.71 and Pentland Ivory yields 4-6t/ha less than Pentland Crown. Of the two siblings which come from parents which have different yielding abilities (Pentland Crown yields 2-9t/ha more than Pentland Dell at the regions) one sibling, Pentland Ivory,

follows the yield trait of Pentland Dell and the other sibling, Pentland Squire, comes closer to the yield ability of Pentland Crown, although Pentland Squire does not match the yield of Pentland Crown neither does it produce such consistent yields at each region.

Pentland Crown has 14 yield correlations (from 36) less than 0.75 and Pentland Dell 9. Pentland Ivory and Pentland Squire have respectively 6 and 9 such correlations. This would suggest that the yield of Pentland Ivory and Pentland Squire interact less with environments than Pentland Crown's yield and that they have inherited Pentland Dell's yield sensitivity, i.e. Pentland Ivory and Pentland Squire are nearer to average sensitivity than Pentland Crown.

Pentland Hawk and Pentland Dell have Roslin Sasumua as a common parent. Both Pentland varieties are highly correlated in their response to regions over years, 0.98, and Pentland Dell has 9 and Pentland Hawk 7 correlations less than 0.75. Thus, these siblings appear to share a similarity in their response to regional effects, but data are lacking on Roslin Sasumua so making inferences about inherited characters untenable.

Pentland Dell, a parent of Croft, has $\hat{\beta}_i$ values above 1.00, as does Croft. However, only Croft has $\hat{\beta}_i$ significantly above 1.00. There are no data on the other parent of Croft, 2895fg, from these trials, so it is not possible to discover if $\hat{\beta}_i > 1.00$ for Croft is due solely to Pentland Dell.

Drayton's yield is poorly correlated with that of Maris Piper (0.63), but well correlated with King Edward's yield, (0.98). This suggests that Drayton has more in common with King Edward than Maris Piper in the way the sibling yields at English regions. In other characteristics (e.g. tuber colour, cooking quality) Drayton is similar to King Edward and this may help to explain the high yield correlation with King Edward and the low yield correlation with Maris Piper. Drayton matches the yield of King Edward at most regions but never out-yields the parent. Maris Piper always out-yields Drayton and the difference in yield varies from 1-7t/ha, which indicates that this variety interacts more with region than Drayton. The cross of a higher and a lower yielding variety has produced a variety which imitates the lower yielding variety - a common incidence in plant breeding.

15.4 Summary.

Varieties appear to follow the yielding trait of one of their parents reasonably well. For instance, Drayton the sibling of a lower yielding variety, King Edward, and a higher yielding variety, Maris Piper, inherited the yield character of the lower yielding parent. Other siblings (Pentland Ivory and Pentland Squire) may follow either of their parents yielding qualities, but without necessarily exceeding or matching the yield potential of the higher yielding parent. Perhaps it is notable that the inter-breeding of Pentlandfield varieties has produced siblings which are included in the Recommended list from parents already listed.

CHAPTER 16

Environment Effects.

16.1 Introduction.

FITCON and AUGFITCON provide methods of estimating environment effects. In complete data the environment effects are measured by the mean yield of varieties grown at each site minus the grand mean yield of all sites. This measure indicates whether a site produces above or below average yields in a given year. Examination of environment effects over several years may indicate (i) environments expected to produce higher or lower than average yields, or (ii) a large variation in site effects.

Varieties should be tested over a wide range of environments to obtain useful estimates of the variety sensitivity. Identification of a group of sites with a consistently wide range of environments would suggest that this group is the most useful to estimate variety sensitivities. Thus, if some sites have to be omitted the omitted sites should not be chosen from this group.

16.2 Method.

AUGFITCON analysis performed on data sets in chapter 7 give environment effects (I_j) as well as variety sensitivities (β_i).

Each year the sum of the environment effects is nought, hence environment effects recorded are relative to other centres.

Blanks in Table 59 are due to sites not being used every year. The analysis was repeated for each year so every row of Table 59 sums to nought but not the columns. The table is arranged with sites grouped by region and increasing order of variability. Sites which exhibit least variation appear furthest to the left of the table. Years which produce the largest environment effect variances appear at the bottom of the table.

The analysis from 1978 is omitted since the environment effects are measured by only five varieties that appear in previous years.

The median environment effect is the mid-environment effect for an environment. This measure indicates whether a particular environment tends to give above or below average yields, (i.e. 'favourable' environments will have a positive median and 'unfavourable' environments a negative median). The semi-interquartile-range (SIQR) is the measure of dispersion of effects about the median.

The range of environment effects for a site indicates how the site responds to a series of years. A small range of environment effects suggests results from that environment are less dependent upon year differences than sites with a wide range of effects. The magnitude of the SIQR will give a further indication of site variability.

16.3 Results

From Table 59 the following results arise:

(i) NC sites give the smallest range of environment effects,

(ii) SW sites give the widest range of environment effects,

(iii) EE sites tend to be unfavourable, at least on half the ocassions used,

(iv) WC sites are generally favourable,

(v) NC sites are generally unfavourable,

(vi) East Riding 'B' has the smallest range of environment effects in EC,

Cambridge has the smallest range of environment effects in EE,

Somerset has the smallest range of environment effects in SW,

and Myerscough has the smallest range of environment effects in WC.

(vii) The ten centres which give the widest range of environment effects are:

North Riding	EC ADAS, median	0.5,	SIQR 6.4
Kent	EE ADAS, median	-3.9,	SIQR 11.6
Terrington	EE NIAB, median	-0.4,	SIQR 6.8
Sutton Bonnington	EE NIAB, median	-4.3,	SIQR 7.6
Seale Hayne	SW NIAB, median	0.6,	SIQR 4.7
Cornwall	SW ADAS, median	12.5,	SIQR 7.9
Harper Adams	WC NIAB, median	0.6,	SIQR 9.2
Lancashire	WC ADAS, median	-0.4,	SIQR 4.6
Rosemaund	WC NIAB, median	2.0,	SIQR 5.7
Cumbria	NE ADAS, median	1.3,	SIQR 6.0

(viii) The centres which give negative effects are:

East Riding 'B'	EC ADAS,	median -9.6, SIQR 0.6
Morley	EE NIAB,	median -8.9, SIQR 6.6
A.Rickwood EHF	EE NIAB,	median -9.2, SIQR 5.8

(ix) Sites which have a favourable effect on yield are:

Cambridge	EE NIAB,	median 3.3, SIQR 2.8
Cornwall	SW ADAS,	median 12.5, SIQR 7.9

(x) To obtain the subset of, for instance, ten centres which produce maximum environment effect variance within each year, the environment effects were ordered and the sites responsible for the five largest and five smallest effects noted, using five years data. The sites which appeared most often in this group were then augmented by those sites which exhibited the next largest range of environment effects. This set of sites was verified by the remaining four years' data and the original set modified if necessary. The set of ten sites which most consistently produces the largest spread (variance) of environment effects within a year is:

Somerset	SW ADAS
Cornwall	SW ADAS
Kent	EE ADAS
Terrington	EE NIAB
Harper Adams	WC NIAB
Headly Hall	EC NIAB
Morley	EE NIAB

Sutton Bonnington	EE NIAB
Seale Hayne	SW NIAB
Cumbria	NC ADAS

16.4 Discussion.

If some sites have to be omitted it may be desirable to use sites that have the widest range of environment effects over years, or produce the greatest variation in environment effects within a year. If the former set of sites is selected, as in (vii) above, the variance components from these sites are similar to those estimated from the entire data set. The estimated variance components are:

$\sigma^2_{VY} = 2.368 \pm 1.300$ and $\sigma^2_{VC} = 1.956 \pm 1.417$.

The overall mean yield is 46 t/ha.

The variance components arising from the ten sites which in general give the highest within year environment effect variance, in (x) above, are:

$\sigma^2_{VY} = 3.013 \pm 2.009$ $\sigma^2_{VC} = 2.278 \pm 2.230$

The overall mean yield is 44 t/ha.

These estimates, although indicating more variation in the component estimates are not different from those estimated from the entire data set or from sites in (vii).

Although the latter set of sites (x) is chosen so it maximises environment effects, the variety x centre component (σ^2_{VC}) is not significantly different from earlier estimates of σ^2_{VC} from the

entire data set. Using these particular centres estimates of variety sensitivity within years would be based on the ten sites which are most likely to give a wide range of environments, but at the same time the variance from the variety x centre interaction is not greatly increased. Thus, this selection of sites does not inflate the variety x environment interaction variance and provides the 'best' set of (10) sites for sensitivity analysis.

The most important aspect of the environments that Table 59 highlights is their variability. Only two sites produce above average effects with much consistency, i.e. 62% of the time, and only four sites consistently below average effects. The size of environment effect varies considerably from year to year,

e.g. Rosemaund has one environment effect of 24.7 but the effects from the other years all lie between -8.1 to 11.3.

'Unfavourable' sites appear in EC, EE(2), and NC. Two favourable sites come from EE and SW. The remaining sites all have medians not sufficiently far from nought for them to be regarded as either favourable or unfavourable.

Western sites produce the widest range of environment effects but do not have dispersions much larger than other sites.

The set of sites that most consistently produces the largest environment effect variance includes all the SW sites, four EE sites but only one site from the remaining regions.

Six sites, Cornwall, Kent, Terrington, Harper Adams, Sutton Bonnington and Cumbria are common to the class of sites with largest environment effects and the class that consistently gives the largest environment variance each year. This result indicates these sites are capable of providing not only a range of environments over time but would ensure that estimates of variety sensitivity within a year are obtained from a wide range of environments.

CHAPTER 17

Analysis of the sites.

17.1 Introduction

The behaviour of the varieties was analysed by a model of the form:

$$\underline{Y} - \underline{\mu}_i = \Theta_1 \underline{u}_{1i} \underline{v}'_{1j} + \Theta_2 \underline{u}_{2i} \underline{v}'_{2j} + \ldots \qquad (a)$$

see chapter 8.

A similar model can be used to analyse the centres,

$$\underline{Y} - \underline{\mu}_j = \Phi_1 \underline{g}_{1j} \underline{h}'_{1i} + \Phi_2 \underline{g}_{2j} \underline{h}'_{2i} + \ldots \qquad (b)$$

where $\Phi = \phi^{\frac{1}{2}}$, the latent root of $\underline{B} = (\underline{Y}-\underline{\mu}_j)(\underline{Y}-\underline{\mu}_j)'$ the centred inner product.

17.2 Method

The variety x centre data tables were completed with estimates for missing entries from AUGFITCON. The modified model of AUGFITCON was not used due to the considerable computing time required to obtain reliable estimates of the second interaction terms.

17.3 Results

The proportion of variation accounted by the first principal component is, with two exceptions, less than 55%. In some years the first two principal components fail to explain half the variation, Table 60.

A plot of the first two principal components from each variety x centre data set produces a scatter of points.

Sites from the same region do not cluster, nor do sites cluster in groups which are consistent from year to year. However, in some years sites from the same region lie on a straight line. The line upon which sites from the same region lie is inconsistent from year to year as is the site order.

17.4 Discussion.

The large amount of scatter in a two dimensional display of environments is expected from the low percentage of variation accounted for by the first two principal components. Only in 1973 does the first principal component account for a substantial proportion of variation, this is reflected in a more orderly patten of the points in Graph 18, compared to Graphs 14-23.

The underlying pattern, or suggestion of a pattern, to environments in the same region in some of Graphs 14-23, e.g. 18 and 22, presents considerable problems of interpretation, but the pattern does suggest that there may be some link between sites in the same region. The lack of consistency over years of the slope of the lines suggests that the association of sites is dependent upon year effects.

Sites plotted furthest from the origin in Graphs 14-23 are those which are most variable (Shukla, 1972). Examination of these sites

does not indicate that SW or WC sites are more variable than sites from other regions. This can be explained by the fact that Graphs 14-23 represent the sites in two dimensions, a dimensionality that still leaves much variation unaccounted. If a three dimensional plot was made WC and SW sites would then, in general, be at a greater distance than other sites from the origin.

A test on the latent vectors to determine how many terms should be included in model (b) to leave only a small proportion of variation unexplained was performed as in chapter 8. This test shows that in most years, 1969 and 1973 excluded, all interaction terms should be included; in 1969 and 1973 two terms are required.

Thus to obtain an adequate representation of the sites many terms in model (b) are necessary. This result contrasts with that from the varieties' analysis where one term accounted for most of the variation, Graphs 24-26. Hence, there is far more variation between centres (also illustrated by low correlations between site yields) than between varieties.

CHAPTER 18

Use of Generalised Lattice designs in potato variety trials.

18.1.1 1979 Experiments.

In 1979 the SPBS Regions Maincrop Trials were planted in generalised lattice (GL) designs. The primary purpose of these trials was to evaluate advanced clones prior to their possible entry in National List Trials (NLT).

Apart from their design the trials were performed in the standard manner. The planting and husbandry (for instance fertilizer application, blight sprays etc.) applied at each trial site was the responsibility of the farm manager.

18.1.2 Site descriptions.

The sites for the trials all have different characters:

Gleadthorpe EHF is located near Mansfield on sandy/gravel soil,

Arthur Rickwood EHF is located near Ely on black fen peat soil,

Terrington EHF is located near King's Lynn on heavy silt loam soil and

The Murrays is located near Pathhead, East Lothian, on heavy silt loam soil.

The elevations of Gleadthorpe EHF, Arthur Rickwood EHF, Terrington EHF and The Murrays are: 50m, 15m, 2m and 122m above sea level respectively.

18.1.3 Design description.

At each site 21 test varieties and three control varieties (Pentland Crown, Maris Piper and Maris Peer) were planted in two super-blocks. The GL design consisted of six blocks of four varieties in each super-block. The efficiency factor of the GL design was 0.6501.

18.1.4 Design layout.

The trial area at Gleadthorpe, Terrington and The Murrays was divided into breaks, of eight drills, and spray-ways, of four drills, which alternated across the field. At Arthur Rickwood (called Rickwood for brevity) each break consisted of twelve drills and spray-ways of four drills. Diagram 1A shows the typical layout of one of these trials. Each plot consisted of four drills of five plants. Adjacent plots were separated by two plants of a coloured variety.

18.1.5 Trial harvest.

At harvest trials were dug by a Bartschi single row digger and tubers gathered by hand. The produce of all 20 plants per plot was graded and the weights of ware (40mm-80mm) and total yield recorded.

18.1.6.1 Results.

At Gleadthorpe EHF one super-block was planted incorrectly so the blocks of the GL design were split. One super-block was thus 24 plots long and one plot wide.

The Rickwood site was attacked by eelworm and yields severely reduced. (e.g. Total yield at Rickwood, 15.5 Kg/plot, at Terrington, 29.3 Kg/plot.)

18.1.6.2 Comparison of Randomised Complete block design and Generalised Lattice design analyses.

A comparison of the analyses of the two designs (Table 2A) shows that the smaller blocks of the GL design reduced the sum of squares associated with the variety and residual sources compared to the randomised complete block design (RCB). That is, some of the variation ascribed to variety differences by the RCB analysis is accounted for by block differences in the GL analysis. This result indicates that the apparent variation between varieties is partly due to within super-block variation. In one trial the residual mean square (RMS) from the GL analysis is larger than the RMS from the RCB analysis. This result occurs because there are fewer degrees of freedom associated with the residual source in the GL than in the RCB analysis.

Table 3A summarises the RMS, standard error (SE), and coefficient of variation (CV) obtained from the two analyses at each site for

ware and total yield. Only one analysis gives the ratio RMS_{RCB}/RMS_{GL} < 100%, which shows that the GL analysis gives a higher RMS than the RCB design.

At The Murrays and Terrington sites there is little difference between the two analyses. From these experiments there seems to be little advantage in analysing the trials as GL designs.

18.1.6.3 Effect of eelworm on results.

The presence of eelworm at the Rickwood site increased the between block heterogeneity and this is reflected in the high ratio between the RMS values from the two analyses, Table 3A. At this site the smaller blocks of the GL design accounted for a much larger amount of uncontrollable variation than the blocks of the RCB design. The simple variety means from the trial are adjusted by the GL analysis more than in the other trials.

18.2.1 1980 Experiments.

The PBI and SPBS amalgamated their Regional Maincrop Trials in 1980. The SPBS gave permission for the trials to be laid out in GL designs and it was responsible for two of the five trials.

18.2.2 Site descriptions.

The trials were located at :Cambridge

Arthur Rickwood EHF

Terrington EHF

Gleadthorpe EHF

The Murrays.

The trials were grown close to the sites used in 1979. The Cambridge trial was located near Trumpington on heavy loam with clay soil at an elevation of 15m above sea level.

18.2.3 Design description.

28 varieties, 24 test varieties and four control varieties (Maris Piper, Pentland Crown, Record and Estima) were laid out in a GL design in three super-blocks; each super-block consisted of seven blocks of four varieties. The efficiency factor of the GL design was 0.7190.

18.2.4 Design layout.

The trials were planted in a similar fashion to the 1979 trials. The plot size in 1980 was four drills of six plants. Each super-block was 14 plots long and two plots wide, thus blocks were two plots wide and two plots long. The produce was scored as in 1979.

18.2.5 Results.

At Gleadthorpe EHF one super-block was wrongly planted, being seven plots long and four plots wide instead of 14 plots long and two plots wide, so the trial could only be analysed as a two

replicate GL design. At Rickwood one replicate was planted with a spray path in the centre of a super-block. The analysis of this trial with three replications showed no significant super-block or block differences so all replicates were retained in the analysis.

18.2.6 Comparison of the GL and RCB analyses.

Comparisons between GL and RCB analyses were made on ware and total yield, Table 4A. In no analysis does the GL analysis give RMS values greater than the RCB analysis. In one comparison the GL analysis gives a similar RMS value to that of the RCB analysis. This result occurs at Cambridge, which is the highest yielding site and the trial grown on the most uniform soil. At the other sites the ratio RMS_{RCB}/RMS_{GL} ranges between 140%-212%, Table 4A.

18.3.1 Demonstration experiment 1979.

There are several differences between trials performed to evaluate test varieties by NIAB and Regional Maincrop trials of the SPBS/PBI. The plot size of NIAB trials is much larger than the plot size used by the SPBS/PBI and the guard rows of NIAB plots are not included in the mean plot yield. NIAB trials are usually replicated four times.

To investigate the effect of using a GL design on a trial based on the NIAB trials, an experiment was planted at The Murrays in 1979.

18.3.2 Design description.

This experiment, laid out in a GL arrangement, used eight varieties in four super-blocks. The GL design subdivided each super-block into two blocks, and had an efficiency factor of 0.8200.

18.3.3 Comparison between NIAB trials and the demonstration trial.

The modal number of varieties in NIAB trials between 1969-1978 is eight, hence eight varieties were used in the demonstration trial. The plot size of the demonstration experiment was four rows of five plants, a typical NIAB plot size is four rows of twenty-five plants. A smaller plot size than the NIAB plot size was used in this experiment due to insufficient seed for larger plots. The smaller plot size allowed harvesting and scoring of the produce to be accomplished in a reasonably short time by one person.

18.3.4 Trial layout and harvest.

Each super-block was four plots long and two plots wide. The varieties in the trial were all on the National List; the two control varieties were Maris Piper and Majestic.

At harvest the centre rows of each plot were dug by a single row digger and the tubers gathered by hand. Tubers were scored and the ware (35mm-80mm) and total yields recorded.

18.3.5 Results.

The comparisons of the two analyses of this experiment (Table 5A) show that the GL design is advantageous compared to the RCB design. The GL analysis gives a lower residual mean square (RMS) and hence explains more of the uncontrollable variation than the RCB design for both ware and total yield. Consequently the standard error (SE) and coefficient of variation (CV) from the GL analysis are smaller than from the RCB analysis.

18.4.0 Results.

The comparisons from the GL and RCB analyses from both years give quite different results. Probably the most important factor which contributes to the different results is the efficiency of the GL designs used. There are also several differences in block size in the two years' trials.

18.4.1 Efficiency of GL designs.

The efficiency factor (E) for GL designs increases as the number of replications (super-blocks) increases. In 1979 the GL design with two super-blocks had an E = 0.6201, in 1980 the design with three replications had an E = 0.7190 and in 1979 the design with four replications had an E = 0.8200. $E_{\star}$, the upper bound of the efficiency factor E, is given by,

$$E_* = \frac{(r-1)(v-1)}{(r-1)(v-1) + r(s-1)}$$

where r = number of super-blocks

v = number of varieties

s = number of varieties per block.

E_* is the efficiency attained if all contrasts confounded in any replication were completely orthogonal to contrasts in other replications. Patterson and Williams (1976) showed that E is generally close to E_* and there is little room for improvement. The efficiency factor E is the reciprocal of the factor which measures the 'increase in variance that results from the division of the variation into sets when the error variance per plot is unaltered by the resultant reduction in block size' (Yates 1936). The higher the efficiency factor the more likely the GL analysis is to be advantageous compared to the RCB analysis. The GL designs with higher efficiency (E) are those that have many replications. As the results of these trials show, a modest increase in the trial size, in replication or variety number, increases the efficiency factor considerably and so the likelihood of the GL analysis giving a lower RMS than the RCB analysis.

18.4.2 Observed advantage of GL designs.

The median value of RMS_{RCB}/RMS_{GL} in 1979 was 107% for ware and 105% for total yield. In 1980 the median values were 141% for ware and 180% for total yield. This result shows a considerable advantage from using the GL analysis in 1980 but little advantage in 1979. Over both years the median ratio is 140% for ware grade and

166% for total yield from eight trials. This ratio of RMS values is comparable with that of 140% obtained from cereal trials (Patterson and Silvey, 1980).

18.4.3 Effect of GL analysis on a NIAB type trial.

The demonstration trial shows that even in a small experiment with small plot size and few varieties the GL analysis can give more precise results than the RCB analysis. The larger plot size used in NIAB trials would encourage increase of the within super-block variation, compared to the plot size used in the demonstration experiment, and so use of a GL design is likely to give more precise results than the standard design. The GL design should give a smaller RMS value than the RCB design since the former design uses smaller blocks.

If the gain obtained in this demonstration experiment (RMS_{RCB} /RMS_{GL} =132%, for ware yield) is typical of the gain to be expected from four replicate trials, then GL analyses will probably be advantageous in NIAB trials compared to RCB analyses.

18.4.4 Difficulties with GL designs.

Contrary to Patterson and Silvey (1980) GL designs appear to be more difficult to use in the field than RCB designs. Three of the nine trials planted were not planted according to the plan. In two cases one super-block was split so that the block structure was destroyed and in one of these trials the super-block planted bore no

relation to the super-block planned. Because resolvable designs have super-blocks indistinguishable from completely randomised replicates, planters, if they think space is short, may 're-arrange' the block to fit the space available. While this 're-randomisation' may not be detrimental to the design when completely randomised blocks are used, such ad hoc re-arrangement of a lattice design may ruin the structure. If GL designs are adopted in potato trials careful supervision will be necessary to ensure the trials are planted according to the plan.

CHAPTER 19

Conclusions.

The conclusions arising from this study of NIAB potato data relate to (1) trial practice, (2) varieties, and (3) environments.

(1) Trial practice.

The variance components computed indicate that in testing potato varieties the number of years over which trials are performed has the most important effect on trial precision.

Variation due to errors in plot measurement and differences between plots contribute least, in a series of trials, to the total variety x environment interaction.

The data indicate that precision of a trial system in detecting variety differences in total yield improves little when the number of centres is increased beyond 15. A substantial improvement may be made to trial precision only by continuing experiments over a greater number of seasons once 15 centres are used.

The number of replications used in each trial has a small influence on variety variance in a series of trials. This fact, however, should not encourage minimal replication, since many replications are important for (i) conserving the accuracy of individual experiments, (ii) accurate estimation of interactions and (iii) ensuring that loss of a replication does not inhibit

estimation of experimental error. Imprecise individual trials cannot lead to high precision of a series of trials; such precision is essential if differences in variety yields are to be detected.

Use of generalised lattice designs in experiments has improved trial precision in detecting yield differences.

(2) Varieties.

Estima shows high interaction with western sites in 1973, a very wet year and Drayton shows high interaction with north of Scotland sites. No explanation has been found for these interactions.

Rainfall is not found to have a consistent effect on yield. Variety yields in a year x region x variety table show a poor linear relationship with rainfall. The relationship is more linear when aggregated data are considered, but the relationship is poorer than that found by McDermott and Ivinns (1955). The different results may be due to changes in cultivation practice which have taken place over the last 25 years.

Variety yield sensitivity to different environments, type E, is found to be unstable over years. Few varieties have a type E sensitivity which indicate that they are specifically adapted to any particular environment. There appears to be a link between type E sensitivity and rainfall during growing season, which suggests there may be no single type E sensitivity for a variety.

The large effect of year differences on variety yields makes yield sensitivity to differences between years, type Y, possibly a more useful indicator of ability to yield consistently than type E sensitivity. Type Y sensitivities are in general agreement with what experience has taught growers about the yielding abilities of varieties.

The type E and type Y sensitivities estimated from our data are not (generally) in good agreement with the corresponding estimates from agricultural data.

The statistical model used on cereal varieties to describe variety sensitivity is also applicable to potatoes, an additional sensitivity parameter accounts for little variation compared to the first.

Comparison of variance components, estimated from similar data to ours, from other crops, indicates that potatoes are not differently affected by year or centre effects. Other crops, such as swedes or barley, are more affected by centre or year effects than potatoes. Thus, despite many dissimilarities between potatoes and other crops there is little difference in the way year and centre variation affect potato yields and those of other crops.

(3) Environments.

Analyses of sites, grouped according to region and soil type, indicate that soil type produces less variation between variety

yields than regions. Higher yielding sites interact with varieties to a greater degree than lower yielding sites. There is considerable variation in variety yield at English regions which makes interpretation of the yields in each region every year difficult. Variety mean yields over years at each region indicate that few varieties out-yield Pentland Crown, and then generally only at wetter sites.

Higher yielding western sites are more variable than eastern sites and this result can be traced back to western trials being the more variable. This difference may result because western sites are generally wetter than eastern sites, and also may be responsible for the wider range of environments produced by western sites. This suggests that western sites are useful in sensitivity analysis if the sensitivity parameter is to be estimated from a wide range of conditions.

Although eastern regions produce less diverse environments (in general), inconsistent correlations between yields at sites in all regions indicate that every site contributes different information about variety yield. This result shows that omission of any site will result in a loss of information about variety behaviour which is not obtained from any other site. In years when rainfall is very high or low the yields at the sites tend to be correlated. In years of average rainfall sites tend to be poorly correlated.

Yields vary more in Scotland than England. There is more variety x region interaction when Scottish sites are included in the

analysis than when they are omitted. These differences are illustrated by the following facts: (i) more varieties out-yield Pentland Crown in Scottish regions than in English regions and (ii) the yields at Scottish regions are more poorly correlated with themselves than with the yields at the English regions. These differences indicate that recommendations from English trials should not be applied to Scotland and vice versa.

A similar set of variance components has been estimated for potatoes from Scottish trials as from English trials. However the component arising from local differences is larger in Scotland than in England. This difference is reflected in lower correlations between the yields at Scottish regions than those between the English regions.

This study, which illustrates the variability of potato trial yields, relates only to the variate total yield. Total yield is only one of the characters considered when varieties are assessed for inclusion on the Recommended/National list. More work is needed to investigate how other important characters are affected by year and centre differences before an overall view of a suitable trial scheme can be obtained. It may take more trials to precisely measure differences in disease resistance than to assess differences in yield. So although there may be little difference in precision between testing variety yields at 15 or 20 sites for three years the difference could be large when disease resistance is considered. Effects of years and centres may be different even when saleable or a graded yield is considered. This work considers only one (but

important) part of variety x environment interaction. It is important that the findings of this study are not applied to other characters normally assessed in variety testing, but not considered here, since the recommendations for other characters could be different.

APPENDIX I

Practical work, other than experiments with Generalised Lattice designs.

PRACTICAL WORK.

Spacing Experiment at The Murrays in 1978.

P.1.1 Aim of the experiment.

The experiment, to examine the effect of three between plant spacing distances on yield, was planted by Dr Killick in the late spring of 1978.

P.1.2 Materials and design.

The varieties: Bintje
Croft
Désirée
Maris Peer
Maris Piper
Pentland Crown
Pentland Hawk
Pentland Javelin
Pentland Squire
Ulster Sceptor

were grown in a split-plot design. The spacings, 9'', 15'' and 21 '' constituted whole-plots and the varieties sub-plots. There were three replications. The plot size was four drills of five setts.

At harvest the produce of each row was scored. The yield was weighed in Kilograms and separated into three fractions: under 40mm, 40mm-80mm and greater than 80mm in length.

P.1.3 Analysis

The standard analysis of variance was performed on the data for a split-plot design. Analyses were carried out on all yield fractions with and without the guard rows' contribution to plot yield.

P.1.4 Results.

The analyses showed a significant difference between yields from varieties at the same spacing and a significant difference in yield of the same variety grown at different spacings, Table S1. These differences were present for all grades of yield, other than chats. The variety x spacing interaction was found to be non-significant. These results were found when border rows were included and excluded from plot yield, Table S2. All tests were made at the 5% level of significance.

P.1.5 Discussion

The non-significant variety x spacing interaction shows that the specific spacing at which these varieties are grown (between 9'' and 21'') does not have a significant effect upon the ranking of the varieties, i.e. there is no varietal effect.

When the border rows are included in the analysis the residual mean square (RMS) is larger compared to when only centre rows were used. This increase in the error variance is due to border rows

giving more variable results than centre rows. Hence, the trial omitting the border rows gives rise to the lower RMS and thus produces more precise results. This result suggests that to gain the most precise results guard rows should be omitted from the trial harvest.

Experimental debris from 1978 split-plot experiment.

P.2.1 Aim

To examine accuracy of trial yields the tubers left after harvest were collected to find how much produce had not been gathered.

P.2.2 Method

The experimental area had been defaced by tractor tyres before the re-pick could take place so the yield collected represents a minimum value left behind. The site of the split-plot experiment was re-dug and all the tubers gathered and put into bags. These bags were marked to correspond to the original plot plan.

P.2.3 Results.

The total weight of produce gathered was 61.7 Kgs., which divided into the three yield grades as shown in Table E1. Most re-pick tubers were in 40mm-80mm grade and the least in the chats grade.

P.2.4 Discussion

The percentage of re-pick weight/harvest weight $\pm$ 2% which is sufficiently small to allow unpicked produce not to affect trial results. The pattern of the produce left behind did not suggest that one part of the trial had more unpicked tubers in it than any other.

It was not possible to assign the re-pick produce satisfactorily to the original plots due to the carry over effect of the potato digger. The re-pick produce per plot was small and the errors in assignment of re-pick produce to plots large. For instance, one empty plot had a re-pick produce of 1.12 Kgs., but the average yield per plot was 0.18 Kgs. No further analysis was performed since these data are unreliable when considered on a plot basis.

The Murrays Experiment, 1979.

P.3.1 Aims.

The primary purpose of this experiment is described in chapter 18 on generalised lattice designs. The way in which this trial was harvested, row by row, enabled the effect of guard rows to be examined.

P.3.2 Method.

The experiment was harvested with a single row digger and the produce from each plot scored. Yield was weighed, in Kgs., in three fractions: less than 35mm, 35mm-80mm and over 80mm in length.

A randomised complete block analysis was performed on the data with and without inclusion of the produce of border rows.

P.3.3 Results.

The analysis of variance tables appear in Tables G1 and G2. The residual mean square (RMS) from the analysis with guard rows omitted gives a lower value compared to that from the analysis when guard rows were included. This result is true for total weight yield and the three yield grades.

P.3.4 Discussion.

The analysis with the guard rows omitted produces the lower error variance term and so this analysis gives more precise results than the analysis based upon results which include guard row produce.

The relationship between total yield and saleable yield as displayed in the 1978 and 1979 experiments.

P.4.1 Aim

This study has been concerned with the variate total yield. Saleable yield, as pointed out in chapter 1, is dependent upon the definition of the fraction and the cultivation employed. The 1978 and 1979 experiments allow the relationship of saleable yield to total yield to be examined.

P.4.2 Method

The definition of saleable sized tubers in 1978 was 40mm-80mm and in 1979 35mm-80mm. The percentage of the total yield in these grades each year appear in Tables R1 and R2. The percentage saleable is given for each of the three spacings used in 1978 since between plant spacings could effect saleable yield.

P.4.3 Results.

As can be seen from Tables R1 and R2 the proportions are much larger in 1979 than 1978. There is not a great deal of variation in the saleable fraction at the different spacings employed in 1978.

P.4.4 Discussion

Tables R1 and R2 highlight the dependence of saleable yield upon definition. The difference in definition is 5mm, 35mm-80mm in 1979 and 40mm-80mm in 1978, and this produces an increase in the saleable proportion of 10%-20%. There will also be a year effect present between the two experiments which will also affect the proportions. Both tables illustrate that 50%-80% of the total yield may be saleable, depending on variety. This shows that total yield need not be a reliable indicator of saleable yield and that inferences made from a trial might change if the variate was saleable yield rather than total yield. The tables also show that total yield is not a constant indicator of saleable yield.

The dependence of saleable yield on definition and cultivation does not make saleable yield a suitable variate to measure when trials from many sites and seasons are to be analysed.

APPENDIX II

Instructions for

Maincrop Potato Trials

organised by NIAB.

Instructions for Maincrop Potato Trials

SEED

Note date and condition on arrival - recording any mechanical or frost damage.

Estimate the % of seed more than 10% of surface area affected by Common Scab, Powert Scab, Skin Spot and Black Scurf.

Record % and discard all seed affected by Gangrene, Dry or Wet Rot both on arrival and during chitting.

Count and tray up seed, rose end uppermost. Chit in the light in a frost free building. All varieties should receive the same chitting treatment. Record date of eyes opening on 50% of tubers. Immediately prior to planting record sprout length, type, distribution and approximate number per tuber.

Closely graded seed should be supplied. If this is not the case please attempt to ensure that the yield rows of each replication of a variety are of similar weight.

LAYOUT

The trial should be laid out as a randomised block with 4 replicates. Details of randomisation of varieties and full trial layout are given in the appropriate page in the notebook.

Only the centre rows of each plot should be harvested for yield purposes, the two outside rows of each plot being considered as discard rows.

Plot size may be varied for local convenience however at least 50 plants must be harvested from each replicate of each variety. Typical plot sizes may be 6 rows by 25 setts or 4 rows by 30 setts allowing for 100 and 60 plants respectively to be harvested from the trial rows.

PLANTING AND CULTURAL

It is desirable to plant the whole trial in one day. If it is necessary to cut the tubers due to a shortage of seed these cut tubers should be planted in the discard rows. Drill width, sett spacing, planting date, cultivations, manurial treatment etc, should be in accordance with local practices. Record these in the appropriate place in the notebook.

If possible avoid post emergence sprays for weed control since these may have differential varietal effects.

OBSERVATIONS DURING THE GROWING SEASON

Record emergence, frost damage and recovery, wind damage, vigour, height, cover, blight, virus or becterial infection, maturity and any other factor affecting the trial.

BURNING OFF

The crop should be burned off at a similar data to the majority of local crops. In 'blight years' it may be considered advisable to burn off the crop when the more susceptible varieties in the trial have achieved a 50-75% level of foliage infection. At least 10 days should be allowed, from the date burned off, before lifting commences.

TUBERS

With a machine harvested trial it is desirable to lift by hand 10 plants from each variety immediately prior to lifting the trial in order to assess the below varietal characteristics. Record depth and spread in soil, firmness of attachment, shape, skin colour and texture, flesh colour, eye depth, appearance. In order to estimate tuber numbers the produce (over 1/2'') of 10 plants per variety per lift should be counted.

LIFTING

The centre rows of each plot should be lifted and the weight of produce recorded in the appropriate place in the notebooks.

GRADING

All produce should be graded on a miminum riddle size of 40mm and a maximum riddle size of 80mm. An intermediate riddle size of 60mm should be also used. Outgraded produce such as cracked and greened tubers should only be recorded on the produce above the 40mm riddle. All weights should be recorded in Kgs in the appropriate column of the yield table.

Indicate a lack of produce in a particular grade by inserting a 0 in the appropriate column. If, for some reason, a particular grade is not recorded delete this column in the yield table.

10 tubers from each replicate of each variety of the 60mm-80mm size grade should be cut and examined for Hollow Heart and Internal Blemish. Record these defects on the appropriate page of the notebook.

STORAGE

If possible retain 1 sack of ware (60-68mm size) from each variety to be stored in a frost free building untill February or March of the next year. Record weight and condition prior to storage.

After the storage period record weight loss, sprount length, type and weight of all diseased material and condition after storage. This data should be recorded separately and dispatched on completion of recording.

GENERAL

This notebook is intended for field use and entries should be made at the time of observation. All notes and comments should be self explantory. If a trial is considered a failure for any reason please notify the NIAB. After the completion of weighings and recordings the prompt return of this notebook to the Potato Branch NIAB would be appreciated.

These instructions quoted above, are sent to all trials officers and they are reproduced here by courtesy of NIAB.

Table 1

A review of affect of husbandry treatments on varietal interactions.

Factor	Varietial interaction	Comments	Reference(s)
Date of planting	Yes	Depends on chitting &year effect- length of season	Munro& Scoury(1977) (1977) Allen(1977)
Between row spacing	No		Jarvis&Shotten (1972)
Between plant spacing	No Yes	May be dependent upon year effects	The Murrays Experiments Wurr(1974)
Fertilizer: N P K	No No No	A general increase in yield only, affect dependent on the season.	Watsen(1963) Van der Paaw (1958)
Different manures	Yes		Fisher & Machenzie(1924)
Date of harvest	Yes	Depends on seed treatment	Toosey(1964)
Chitting/ physiological age	No Yes		Allen(1978) Bursal(1980)
Seed size	Yes	No effect if all varieties have the same seed size	Kirenko(1977) Wurr(1971)
Plant pop./ stem density	Yes No		Jarvis (1971) Boyd & Lessels (1954)
Seed Storage regime	Yes		Toosey(1964) Allen et al (1979)
Pest attack	No		Large(1959)
Nematode attack	No		Trudgill et al (1975)

Factor	Varietial interaction	Comments	References(s)
Source of seed	Yes		Kawakawi(1952)
Temperature in store	Yes		Toosey(1964)
Radiation	No		Allen(1980)

Table 2

The proportion of plants used in side guard rows when 120 plants are planted in different plot shapes.

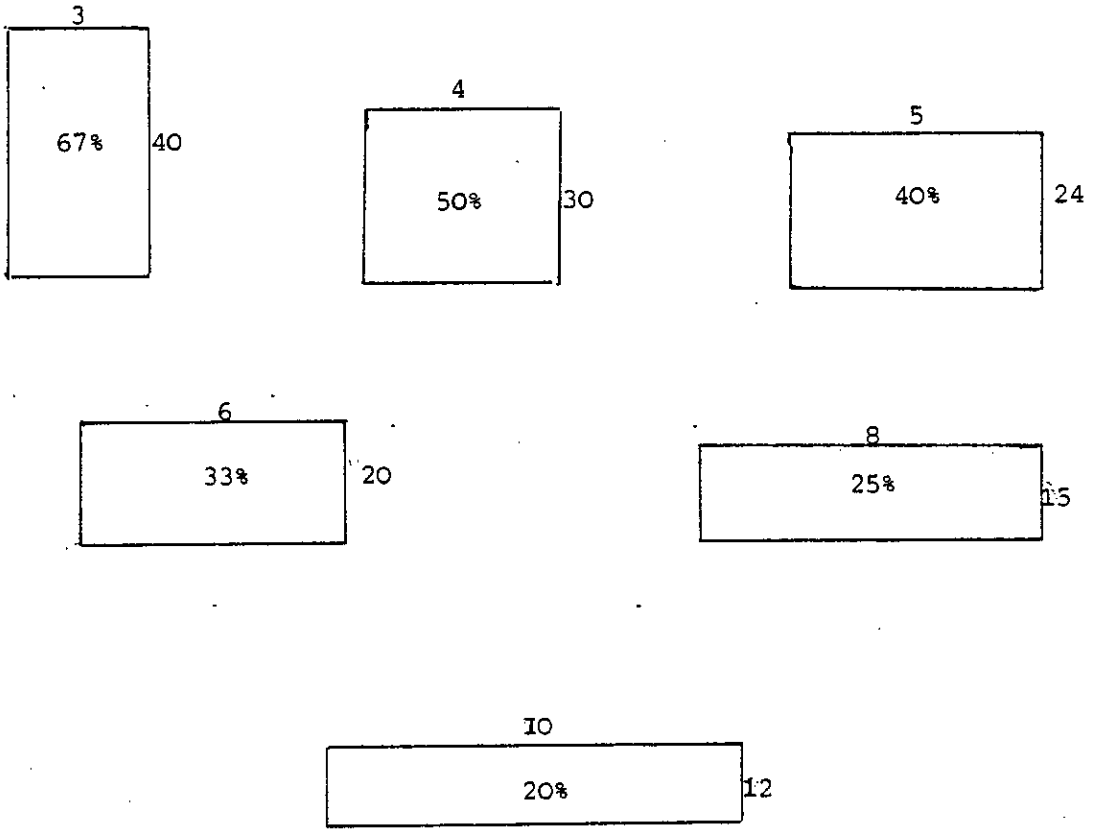


Table 3

A review of recommended plot shape, size and replication number in variety trials.

Crop	Plot shape	Plot size	Number of replications
Potatoes[1]		506-1012m	max. of 5
Potatoes[2]		81-1620m	4
Mangolds[3]	L and S	81-101m	
Potatoes[4]	L	25-50m	4
Potatoes[5]	L	25 hill single row	4 or 5
Potatoes[6]	L	12.2m row 11.0-14.6m max.	4 or 5
Potatoes[7]		11.0m single row	4
General[8]		4 rows wide	
Potatoes[9]	L	4 or 5 rows x 29.8m	
Potatoes[10]	L	4 rows x 20.1m	
Potatoes[11]		30.2 single row plot	
Potatoes[12]	L and S	27.4m divided into shorter rows	4 or 5
Potatoes[13]		2.2m rows	
Potatoes[14]	L	Depends on required accuracy	
Potatoes[15]	L	Depends on required accuracy	min. of 5

Notes: L = long narrow plots
S = square plots
Super-scripts refer to the references, given overleaf.

References to Table 3.

Reference number	Reference
1	Wood,T.B., Stratton, F.J., Interpretation of experimental results. J.Agric.Sci. (1910) 3 417-559
2	Lyttle-Lyon, T., Some experiments to estimate errors in field plot tests. Proc.Amer.Soc.Agron. (1911) 3 89-114
3	Mercer,W.B., Hall,A.D., Experimental error in field trials. J.Agric.Sci. (1911) 4 107-127
4	Mitscherlich, A.E., Feldversache mit kartoffen (Potato Field Trials) Landw-Jahrb (1919) 54 703-745
5	Meyers, C.H., Perry, F.R., Analysis and interpretation of data obtained in comparative tests of potatoes. J.Am.Soc.Agron. (1923) 15 239-253
6	Westover, K.C., The influence of plot shape and replication on experimental error in field trials with potatoes. W.Va.Agr.Exp.Sta.Bul. (1924) 189
7	Livermore, J.R., A critical study of some factors concerned in measuring the effect of selection in the potato. J.Amer.Soc.Agron. (1927) 857-896
8	Christidis, B.G., The importance of shape of plots in field experimentation. J.Agric.Sci. (1931) 21 14-37
9	Justesen, S.H., Influence of size and shape of plots on the precision of field experiments with potatoes. J.Agric.Sci. (1932) 22 366-372
10	Kalamkar, R.J., Experimental error and the field-plot technique with potatoes. J.Agric.Sci. (1933) 22 373-383
11	Currance, F.M., Krantz, T.M., the relation of plot size and shape to potato yield. Am.Pot.Jour. (1936) 310-313
12	Thompson. R.C., Size, shape and orientation of plots and number of replications required in sweet potato field plot experiments. J.Agric.Res. (1934) 48 379-399
13	Hoyle, B.J., Baker, G.A., What is the best sample size for evaluating potato plots. (Mimeo) Univ. of Calif. (1960)
14	Nonneck, I.L., Smillie, K.W., Precision of field experiments with vegetable crops as influenced by plot size and shape. III. Potatoes. Can.J.Plant Sci. (1964) 44
15	Killick, R.J., Personal Communication (1979). Unpub. data

Table 4

The residual mean sum of squares (RMS) arising from the analysis of NIAB potato trials grouped by the number of varieties per block. Each trial had four blocks, each planted using the same between plant spacing.
Variate: total yield, t/ha.

North Central Sites

	No. of varieties per block			
RMS	⩽ 8	9-11	12-14	15 ⩾
0-12	3	3	1	0
> 12	4	2	2	3

χ^2 not significant at the 10% level

East Central Sites

	No. of varieties per block			
RMS	⩽ 8	9-11	12-14	15 ⩾
0-12	4	3	2	4
> 12	10	5	2	0

χ^2 significant at 10% but not 5% level

East of England Sites

	No. of varieties per block		
RMS	⩽8	9-11	12 ⩾
0-12	13	8	20
12-24	2	9	5
> 24	2	4	1

χ^2 Sig. at the 5% level

South West Sites

	No. of varieties per block		
RMS	⩽8	9-11	12⩾
0-12	2	3	2
12-24	4	4	2
> 24	1	6	3

χ^2 NS at the 10% level

West Central Sites

	No. of varieties per block			
RMS	⩽8	9-11	12-14	15⩾
0-12	6	2	1	3
12-24	12	6	0	4
> 24	8	5	7	6

χ^2 Sigificant at 25% level but not at 10% level

Table 5

Integration of breeders, NIAB, ADAS and PMB work on new varieties.

Year	Testing Body	Nature of trial	No. of Sites	Action
1	NIAB	Observational plots of breeder's material (1)	HQ	Report to breeder
2	NIAB	Obersvational plots of breeder's material (2)	HQ	Report to breeder for entry into National List trials.
3	NIAB/DAFS /DANI	National List Trial (1) Trial imput from UK sites.	3	Report to UK Departments
4	NIAB/DAFS /DANI	National List Trial (2) Trial imput from UK sites.	3	Decision by UK Departments Publication of NIAB Classified List.
	NIAB	Recommended List Trial(1)		Report to PTAC
5	NIAB/ADAS	Recommended List trial(2)	20	Report to PTAC
	PMB	Seed multiplication for Comm'l Assessemnt trials	1	
6	NIAB/ADAS	Recommended List trial(3)	20	Consideration for provisional (P) Recommendation
	PMB	Comm'l Assessment trial(1)	1	Report in NIAB Journal
7	PMB	Comm'l Assessment trial(2)	4	Report in PMB booklet
	NIAB/PMB	Secondary trial on 'P' varieties (1)	5	Report in PMB booklet
8	NIAB/PMB	Secondary trial on 'P' varieties (2)	5	Unconditional recommendation or removal from list.

The data in this study come from years 4, 5 and 6 in the testing scheme above.

PTAC : Potato Trials Advisory Committee
HQ : NIAB head quarters, Cambridge

(This edited table is reproduced by courtesy of NIAB.)

Table 6

A list of the varieties in NIAB maincrop potato trials, 1969-1978, with the number of trials in which each variety appears, and the number of years over which the variety was tested.

Variety	Number of years	Total number of trials
Baraka	2	6
Bintje	1	1
Black Queen	1	5
Brio	1	1
Burman	1	1
Cara*	5	37
Clada*	5	37
Commer	2	14
Corrie*	2	24
Croft*	5	58
Désirée*	10	143
Drayton*	4	54
Drmac	2	2
King Edward*	10	188
Estima*	6	75
Estimo	1	1
Famosa	2	13
Gracia*	2	21
Grandi	2	14
Helina	2	5
Intock	2	13
Irene	1	1
Majestic*	10	139
Maris Barca	1	1
Maris Court	1	6
Maris Piper*	8	54
Martia	2	11
Monitor*	4	18
OakPark Amber*	5	24
Orion	1	9
Paragon*	6	61
Patrones*	2	29
Pentland Crown*	9	152
Pentland Dell*	8	38
Pentland Hawk*	7	50
Pentland Ivory*	10	105
Pentland Raven*	4	31
Pentland Squire*	5	29
Picolo	1	18
Record*	10	94
Rector	2	14
Regiment	2	11
Romano	1	2
ROP	1	1
Satura	2	9
Sinead	1	1
Stormont Enterprise*	10	124
Spartaan*	2	30

Variety	Number of years	Total number of trials
Splendor*	4	26
Spunta	2	12
Strath*	3	26
Thyina	2	15
Ulster Brevet*	3	46
Ulster Lancer*	5	26
Wilja	2	13
Woudst	3	13
DH207	1	1
DHS64207/21*	3	44
DHS66	2	2
DHS398	1	15
HO/48*	6	50
Q10/1	3	3
S62/47/1*	5	56
TSC6109	1	2
1210/3	1	2
1225a3*	5	42
219/5	1	9
253264	1	15
4/15	1	4
431b3*	2	21
43163	2	17
466B4	1	10
477/1*	4	40
60/281	2	6
61/42	1	2
61/101	1	4
65/38	1	2
694/3*	3	27
904b29	2	7
916/4*	5	45

* indicates the varieties included in the analyses.

Table 7

A list of the sites used in the NIAB potato maincrop trials, 1969-1978, and the number of years that each site was used.

Site	Code	Number of years used
Cambridge*	1	9
Cockle Park*	2	10
Harper Adams*	3	10
Headley Hall*	4	10
Morley*	5	10
Myerscough*	6	10
Rosemaund*	7	10
Seale Hayne*	8	10
Sutton Bonnington*	9	10
Terrington*	10	10
Anglsey	11	1
Cornwall*	12	7
Cumbria*	13	10
Devon	14	1
Durham*	15	8
Norfolk East	16	3
Isle of Ely	18	2
Kent*	19	10
Lancashire*	20	10
Linconshire	21	2
Norfolk	22	2
North Riding*	23	8
Pembroke	24	1
Arthur Rickwood*	25	4
Somerset*	26	9
West Midlands	27	2
East Riding 'A'*	17,28	9
East Riding 'B'*	29	4
Derby	30	1
Leicester	31	1
Scampton	32	1
Scarcliff	33	1

* indicates that the site was included in the analysis.

Table 8

Extent of yield data used in the analysis of NIAB potato trials, 1969-1978.

Site division	No. of varieties	No. of centres	No. of years	No. of trials	No. of variety means
NIAB 1969-1973	27	10	5	50	556
ADAS 1969-1973	18	8	5	36	298
NIAB 1974-1978	31	10	5	49	700
ADAS 1974-1978	29	10	5	43	394
All sites 1969-1978	36	20	10	178	1948
East Central(EC)	36	4	10	31	316
East England(EE)	36	6	10	53	675
North Central(NC)	36	3	10	28	267
South West (SW)	36	3	10	26	249
West Central(WC)	36	4	10	40	459
Soil type 2	36	4	10	39	394
Soil type 3	36	4	10	57	726
Soil type 4	36	5	10	41	418

Notes: See Table 10 for NIAB soil type classifications.

Table 9

Details of Experimental sites used in NIAB maincrop trials, 1969-1978.

Code	Centre	Region	Soil type	Site Class
4	Headley Hall	EC	3	NIAB
23	North Riding	EC		ADAS
28	East Riding 'A'	EC	2	ADAS
29	East Riding 'B'	EC		ADAS
1	Cambridge	EE	3	NIAB
5	Morley	EE	2	NIAB
9	Sutton Bonnington	EE	3	NIAB
10	Terrington	EE	4	NIAB
19	Kent	EE	4	ADAS
25	A.Rickwood	EE		ADAS
8	Seale Hayne	SW	3	NIAB
12	Cornwall	SW	4	ADAS
26	Somerset	SW	4	ADAS
3	Harper Adams	WC		NIAB
6	Myerscough	WC	3	NIAB
7	Rosemaund	WC	4 (1974-78)	NIAB
20	Lancashire	WC		ADAS
13	Cumbria	NC	2	ADAS
2	Cockle Park	NC	2	NIAB
15	Durham	NC	3	ADAS

No. of sites in EC : 4
EE : 6
NC : 3
SW : 3
WC : 4

No. of sites with soil type 2 : 4
3 : 6
4 : 5

Table 10

NIAB soil codes.

Soil code 2 refers to: Loamy sand - fine
- very fine
Loamy soils - sandy loam
- sandy loam coarse

Soil code 3 refers to: Loam
Sandy clay loam
Clay loam
Silty clay loam
Sandy clay
Silty clay
Clay

Soil code 4 refers to: Silty loam
Silt loam
Sandy loam - fine
- very fine

Table 11

Estimated components of variance for total yield (t/ha) of potato tubers from NIAB trial data.

Data	Variance Components			
	V x Y	V x C	V x C x Y	Plot error
1969-1973				
NIAB	1.5203±0.8992	2.1989±1.0825	13.5023±1.4073	16.6977
ADAS	0.6625±0.9975	2.8530±1.5522	11.1355±1.7327	16.8918
1974-1978				
NIAB	5.8170±1.7080	2.5881±1.1264	14.0723±1.3834	19.6770
ADAS	0.0000±1.1262	4.8786±2.8382	21.2593±12.8237	22.5263
(10 sites)				
ADAS	0.0000±1.4558	3.0017±2.9580	23.5431±3.6113	24.3995
(8 sites)				
1969-1978				
All sites	2.6256±1.2508	2.9808±1.5252	14.9616±1.7350	18.7866
East Central	1.6255±1.3396	1.8313±1.3402	9.3577±1.6441	16.4537
East England	4.3473±1.2047	1.4747±0.7792	11.2584±1.0504	11.6440
North Central	2.3073±1.8416	3.3897±1.9314	9.9828±1.9295	16.1118
South West	2.0938±4.0690	6.0256±4.8929	25.1463±4.5906	24.1980
West Central	2.1478±1.8053	0.0000±1.1272	21.6964±2.6177	29.1707
Soil type 2	1.3136±1.4036	3.4922±1.7659	14.2572±1.8929	16.3504
Soil type 3	3.0243±1.0200	1.1283±0.7442	13.3797±1.2537	19.4120
Soil type 4	0.0000±1.1654	4.4080±2.2294	17.4014±2.1639	16.8799

Table 12
Components of variance for total yield of potato tubers, (t/ha) .

Source of data	Variance of a variety mean	Percentage of variance of a variety mean σ^2_{VC}	σ^2_{VY}	σ^2_{VCY}	$\sigma^2_{\varepsilon}/4$	Grand mean (t/ha)	CV %
NIAB centres	24.74	10	16	56	18	46.2	9.3
ADAS centres	26.22	15	1	64	20	45.3	9.9
All trials	25.26	12	10	59	19	45.9	9.4

Table 13
Components of variance for total yield of potato tubers, (t/ha) .

The data have been split by grouping together sites which have a similar soil type. (NIAB soil codes were used.)

Source of data	Variance of a variety mean	Percentage of variance of a variety mean σ^2_{VC}	σ^2_{VY}	σ^2_{VCY}	$\sigma^2_{\varepsilon}/4$	Grand mean (t/ha)	CV %
Soil type 2	23.15	15	6	61	18	43.9	9.2
Soil type 3	22.38	4	14	60	22	45.3	9.7
Soil type 4	26.03	17	0	67	16	48.3	5.9

The tables express each variance component as a percentage of the total genotype x environment variance.

Data come from the 1969-1978 NIAB maincrop potato trials.

Table 14

Components of variance for total yield of potato tubers, (t/ha) .

The data have been split by grouping together sites which appear in the same region. (NIAB regional boundaries were used.)

Source of data	Variance of a variety mean	Percentage of variance of a variety mean σ^2_{VC}	σ^2_{VY}	σ^2_{VCY}	$\sigma^2_{\varepsilon}/4$	Grand mean (t/ha)	CV %
East Central	16.93	11	10	55	24	43.8	9.3
East England	19.99	7	22	56	15	42.7	8.0
North Central	19.71	17	12	51	20	44.6	9.0
South West	39.32	15	5	64	16	49.6	9.9
West Central	31.14	0	7	70	23	48.1	11.2

The table expresses each variance component as a percentage of the total genotype x environment variance.

Table 15

Variance of a variety mean of total yield of potato tubers (t/ha).

The contribution of the variance components to the total variance of a variety mean, V, when the trial resources are altered. The variance components are estimated from the entire data set of NIAB potato trials.

No .of years	No .of centres	No .of reps.	V	Percentage of V			
				σ^2_{VY}	σ^2_{VC}	σ^2_{VCY}	σ^2_{ε}
1	1	4	25.26	10	12	59	19
1	30	4	3.38	78	3	14	5
1	20	4	3.76	70	4	20	6
2	10	4	2.44	54	6	30	10
2	10	8	2.33	57	6	32	5
3	10	4	1.83	48	16	27	9

Table 16

Critical %differences d(0.025) in yields of potato trials.

Data: All years, all centres, all varieties, from NIAB trials, 1969-1978.
The table below assumes four replications per trial, and two control varieties.

No. of centres	Number of years 1	2	3	4	5
1	26.3	19.6	16.9	15.3	14.3
2	19.5	14.5	12.4	11.2	10.4
3	16.7	12.4	10.5	9.5	8.8
4	15.0	11.1	9.4	8.5	7.8
5	14.0	10.3	8.7	7.8	7.2
6	13.2	9.7	8.2	7.3	6.8
7	12.6	9.3	7.8	7.0	6.4
8	12.2	8.9	7.5	6.7	6.2
9	11.8	8.6	7.3	6.5	5.9
10	11.6	8.4	7.1	6.3	5.8
15	10.6	7.7	6.4	5.7	5.2
20	10.1	7.3	6.1	5.4	4.9
25	9.8	7.1	5.9	5.2	4.7
30	9.6	6.9	5.7	5.0	4.5
35	9.5	6.8	5.6	4.9	4.4
40	9.3	6.7	5.5	4.8	4.4
∞	8.5	6.0	4.9	4.2	3.8

The underlined figure indicates the critical difference attained by the present system.

Table 17

Acceptance Probabilities.

The required probabilities of acceptance of varieties with true mean differences δ are given by F(x) with $x = 1.96(\delta - 2.5)/\hat{d}(0.05)$ where $\hat{d}$ comes from the table of critical differences.

Trial system A : 2 control varieties, 20 sites for 3 years - Present system.

B : 2 control varieties, 15 sites for 3 years

C : 2 control varieties, 20 sites for 2 years

D : 2 control varieties, 30 sites for 2 years.

Acceptance probabilities for the 4 trial systems described above:

Variety mean yield (as % of control mean)
(critical difference = 2.5%of mean of two controls)

System	95	97.5	100	102.5	105	107.5	110
A	0.008	0.053	0.211	0.5	0.789	0.946	0.992
B	0.011	0.064	0.222	0.5	0.778	0.936	0.989
C	0.022	0.090	0.251	0.5	0.749	0.910	0.978
D	0.017	0.078	0.239	0.5	0.761	0.922	0.983

Table 18

A review of estimated components of variance for some agricultural crops.

Crop	σ^2_{VC}	σ^2_{VY}	σ^2_{VCY}	σ^2_{ε}	Yield/ units
[1]Oats[1]	0.042	0.004	0.075	0.082	4.7t/ha
[10]Oats[4]	0.3	4.05	10.332	27.231	lb/acre
[2]Spring Wheat[1]	0.02	0.03	0.06	0.07	4.6t/ha
[4]Winter Wheat[1]	0.005	0.023	0.121	0.108	5.5t/ha
[6]Wheat[2]	1158	241	2872	3394	gm/2.3m
[8]Wheat[4]	1.717	0.186	8.663	6.357	lb/acre
[11]Wheat[5]	2.10	3.26	12.74	21.71	dkg/plot
[12]N.P. Wheat[6]	19.244	0.000	8.359	109.812	?
[13]New Wheat[6]	3.376	1.045	2.079	15.217	?
[3]Spring Barley[1]	0.008	0.032	0.056	0.110	5.0t/ha
[7]Barley[3]	0.22	3.99	15.97	42.78	bushels/acre
[9]Barley[4]	5.222	2.293	16.567	5.059	lb/acre
[14]Flax[7]	63.9	0.0	802.58	1098.5	gm/10m row
[15]Soy Beans[8]	0.08	0.05	0.42	0.39	kg/(1/100ha)
[16]Soy Beans[8]	0.09	0.12	0.50	0.76	kg/(1/100ha)
[17]Fall Rye[9]	44887	26321	203373	210820	kg/ha
[20]P.R.G. 1[11]	0.047	0.013	0.078	0.327	11.43t/ha
[21]P.R.G. 2[11]	0.057	0.017	0.021	0.263	9.1t/ha
[22]P.R.G. 3[11]	0.071	0.092	0.605	0.631	14.8t/ha
[23]P.R.G. 4[11]	0.184	0.065	0.537	0.468	12.6t/ha
[24]Swedes[11]	0.002	0.081	0.116	0.493	7.05t/ha
[25]Spring Beans[11]	0.004	0.015	0.049	0.074	3.7t/ha
[5]Potatoes	2.98	2.63	14.96	18.79	45.9t/ha
[18]Potatoes[10]	705	0	25.216	168124	gm/hill
[19]Potatoes[11]	1.886	1.868	3.919	32.458	t/ha

Notes:

The right superscript in the 'Crop' column is the key to the reference from which the figures are taken. When this superscript is absent the figures come from this study.

The left superscript in the 'Crop' column is the key to Table 19, so allowing a cross reference between the two tables.

Abbreviations: P.R.G.1 'Frequent' management of perennial ryegrass in first year of harvest.
P.R.G.2 'Frequent' management of perennial ryegrass in second year of harvest.
P.R.G.3 'Conservation' management of perennial ryegrass in first year of harvest.
P.R.G.4 'Conservation' management of perennial ryegrass in second year of harvest.

References to Table 18.

Reference number in the table	Reference
1	Patterson, H.D., Silvey, V., Talbolt, M., Weatherup, S.T.C., Variability of cereal varieties in U.K. trials. J.Agric.Sci. (1977) 89 239-245
2	Baker, R.J., Genotype x environment interaction in yield of wheat. Can.J.Plant Sci. (1969) 49 743-751
3	Lambert. J.W., Rasmussen, D.C.,Variety x environment interactions in barley variety tests. Crop Science (1969) 1 261-2
4	Liang, G., Heyne, E., Walter, T.,Estimates of variety x environment interactions in yield tests of 3 small grains and their significance on the breeding programs. Crop Science (1966) 6 135-139
5	Pesk, J., Baker, R.J.,An application of index selection to the improvement of self pollinated species. Can.J.Plant Sci. (1970) 50 267-276
6	Gandhi, S., Nathawat, K., Bhatnayar, V., Variety x environment interaction in wheat variety tests in Rajasthan. Ind.J.Genetics& Pl.Breeding (1964) 24 36-41
7	Tyson, H., Bradner, N.,Interaction of variety and environment in flax trials. Can.J.Plant Sci. (1967) 47 441
8	Schutz, W., Bernard, R.,Genotype x environment interactions in the regional testing of soybean strains. Crop Science (1967) 7 125
9	Kaltsikes, P.J., Genotype x environment interaction variances in yield trials of Fall Rye. Can.J.Plant Sci. (1970) 50 77-80
10	Sekioka, T., Lauer, F.,Some estimates of genotype x environment interactions in potato variety tests. Am.Pot.Journal (1970) 47 304-309
11	Talbot, M., Unpublished data. Per.Comm. (1980)

Table 19

A review of some estimated ratios of variance components.

Crop	$\sigma^2_{VY}/\sigma^2_{VC}$	$\sigma^2_{VCY}/\sigma^2_{VC}$	$\sigma^2_{\varepsilon}/\sigma^2_{VC}$
N.P. Wheat[12]	0.000	0.434	5.706
Potatoes[18]	0.000	35.767	238.474
Flax[14]	0.00	12.57	17.20
Oats[1]	0.082	1.769	1.932
Wheat[8]	0.108	5.045	3.702
Wheat[6]	0.208	2.480	3.931
P.R.G. 1[20]	0.270	1.662	7.006
P.R.G. 2[21]	0.295	0.369	4.650
New Wheat[13]	0.310	0.616	4.507
P.R.G. 4[23]	0.356	2.923	2.546
Barley[9]	0.429	3.172	0.969
Soybeans[15]	0.62	5.25	4.87
Potatoes[5]	0.881	5.019	6.302
Potatoes[19]	0.990	2.078	17.210
Spring Wheat[2]	1.129	2.344	2.695
P.R.G. 3[22]	1.294	8.541	8.908
Soybeans[16]	1.33	5.56	8.44
Wheat[11]	1.55	6.07	10.34
Spring Beans[25]	3.477	11.136	16.818
Spring Barley[3]	3.833	6.679	13.107
Winter Wheat[4]	4.633	24.674	22.082
Oats[10]	13.052	33.329	87.842
Barley[7]	18.14	72.59	194.45
Swedes[24]	33.583	48.208	205.417

See notes to Table 18.

Table 20

Observations detected as outlying values in variety x centre tables from NIAB potato trials.

Variate: total yield, t/ha.

Year	Site	Variety	Observed value	Estimated value
1971	Seale Hayne	Pentland Ivory	63.8	40.7
1972	Lancashire	King Edward	61.8	75.3
1973	Harper Adams	Estima	73.6	57.8
	Harper Adams	Paragon	75.4	65.8
	East Riding 'A'	King Edward	27.0	42.7
1974	Cambridge	Estima	51.4	67.1
	Myerscough	Estima	97.0	73.4
1975	Cornwall	Cara	53.3	81.2
	Somerset	Cara	58.4	32.5
	Cumbria	Paragon	65.1	47.1
1976	Seale Hayne	Cara	55.0	38.0
	Rickwood	Cara	46.4	28.1
	Myerscough	Clada	26.8	47.6
1977	Harper Adams	DH/21	40.8	67.9
	Harper Adams	Strath	44.0	63.1

Estimated values come from the FITCON model, see chapter 6.

Table 21

Coefficients of variation arising from NIAB maincrop potato trials, 1969-1978.

Region	EC				EE						SW			WC				NC		
Site Code	23	28	4	29	19	10	9	5	25	1	8	12	26	3	20	7	6	13	2	15
Year																				
1976	17	8	12	22	8*	6	11	10	18	14	16	7	x	12	14*	14*	11*	14	10	x
1975	9	11	6	11	19	6	14	9	7	8	18*	6	12	22	16	6	13	18*	9	x
							16													
1978	x	17*	6	6	6	8	3	9	8	x	9	5	10	8	8	9	9	11	6	9
1974	7*	10	6	x	10	7	10	6	x	6	12	9	9	10	6	15	11	6	6	7
							6													
1977	x	11*	8	9	8*	5	5	9	14	5	8	6	10	7	20	11	15	10	9	8
1970	9	22	6	x	12	7	11	8	x	9	11	x	9	23	7	7	13	7	6	5
1972	8	10	6	x	9	7	6	9	x	6	23*	10	12	5	8	12	10	7	12	10
							7													
1971	8	x	8	x	15	5	5	7	x	6*	15	x	12*	10	8	11	6	6	8	10
			11				5	6						7		12	10		7	
1969	9	8	7	x	11	7	11	13	x	6	7	x	7	10	10	14	13	9	6	11
					7															
1973	6*	11*	9	x	5	4	6	6	x	6	8*	7	5	6	7	14	13*	6	6	9*
			9				6			6										

All coefficients are given as percentages.
x indicates that the site was not used in a particular year.
* indicates that the trial was analysed with at least one value estimated.
At some sites two trials were performed, in such cases both coefficients are given.
The years are ordered with the wettest at the bottom of the table.
See Table 9 for site codes.
The sites are ordered with highest yielding site in each region on the right.

Table 22

FITCON residuals x 10 from the 1975 NIAB potato trial data.
Variate: Total yield, t/ha.

Site codes	26	3	10	9	5	29	19	25	1	4	8	13	2	28	6	20	7	23	12
CARA	263	78	20	*	18	-45	6	66	-53	-43	-25	-15	58	106	-50	-101	-63	33	-254
CRIE	*	1	10	-5	18	*	-21	99	13	-27	-9	*	13	*	-58	*	-33	*	*
CRFT	-5	-27	-86	18	-29	14	-23	-11	21	-13	24	9	-72	86	33	*	19	-39	19
DSIR	-24	-99	32	-34	51	0	4	14	-3	-9	0	109	2	-56	7	-15	-11	5	27
DYTN	24	36	28	8	-2	45	-41	-10	12	-4	-54	-86	21	17	-15	11	48	7	-44
EDWD	-4	3	28	93	-64	51	-33	-59	-10	29	-1	-121	45	-18	26	-27	-8	-2	72
ESTM	-44	-13	-26	*	-44	-25	-31	0	64	43	-98	74	35	-3	6	-8	21	72	-23
MJST	-24	79	10	61	-26	*	25	-57	-6	41	-28	-63	51	-77	34	-17	-1	49	-52
MNTR	*	-28	-11	-81	34	*	*	*	37	14	57	*	-80	*	83	*	-26	*	*
AMBR	*	13	-40	*	-4	*	*	*	12	-6	17	*	-18	*	26	*	0	*	*
PRGN	-170	*	*	*	*	-73	*	-89	*	*	*	163	*	27	*	56	*	-7	94
CRWN	25	-67	7	-97	84	-3	30	78	-11	-31	1	10	-5	-61	-28	-8	1	14	59
RAVN	*	-22	-19	*	8	*	*	-14	7	-63	45	*	-2	*	37	*	27	*	*
RECD	*	-25	6	42	-59	*	*	*	-1	2	52	*	6	*	10	*	-34	*	*
SNTP	*	44	10	*	42	*	*	*	*	3	20	*	-85	*	-47	*	13	*	*
SPND	*	-31	2	-6	-4	*	40	-54	35	14	19	*	-4	*	-31	*	21	*	*
STRA	*	11	9	*	*	*	*	*	-16	33	*	*	*	*	-38	*	*	*	*
DH21	*	69	4	*	*	*	*	*	-67	2	*	*	*	*	-9	*	*	*	*
HO48	-18	*	*	*	*	10	*	5	*	*	*	-11	*	-15	*	71	*	-59	18
4771	-23	-23	17	*	-22	0	69	34	-35	18	-21	-68	36	-7	13	39	25	-72	23

See Table 9 for site codes and Table 61 for variety abbreviations.

The sites are ordered so that the lowest yielding sites appear on the left.

Table 23

FITCON residuals x 10 from the NIAB potato trial data.
Variate: Total yield, t/ha.
The sites are ordered with the lowest yielding sites on the left.

Site codes	5	13	26	9	12	25	19	8	4	2	6	15	29	7	20	10	3	28
DSIR	-3	29	*	*	20	-20	22	52	-30	-44	*	-39	3	-33	43	*	*	*
EDWD	1	12	-33	-4	-8	-27	-43	-47	25	19	26	45	15	-31	16	75	-9	-30
CRWN	3	-41	33	4	-12	-18	14	-19	-3	5	-14	-6	-18	64	-59	-34	70	30
RECD	*	*	*	*	*	-2	7	*	5	-6	2	*	*	*	*	-7	1	*
9164	*	*	*	*	*	66	*	14	3	26	-13	*	*	*	*	-33	-63	*

See Table 9 for site codes and Table 61 for variety abbreviations.

The sites are ordered with the lowest yielding sites on the left.

Residual mean square from the table is 3.2 times the plot error.

Table 24

FITCON residuals x 10 from the 1973 NIAB potato trial data.
Variate: Total yield, t/ha.

Region	NC	NC	NC	WC	WC	WC	WC	SW	SW	SW	EC	EC	EC	EE	EE	EE	EE	EE
Site code	2	13	15	7	6	20	3	8	26	12	28	23	4	19	1	9	5	10
CARA	*	*	*	*	58	*	-112	*	*	*	*	*	5	*	-20	31	*	38
DSIR	16	-9	6	-50	-61	16	124	-1	-45	25	35	-31	-35	41	15	-34	-9	-3
DYTN	*	*	*	*	20	*	-101	*	*	*	*	*	-44	*	36	53	*	36
EDWD	36	12	-25	-23	16	-63	-61	70	36	22	-127	-35	28	12	-13	42	16	58
ESTM	*	*	*	*	-60	*	187	*	*	*	*	*	-52	*	7	-41	*	-41
MJST	48	20	10	11	-20	-36	-28	-11	13	0	12	-33	13	-7	-4	20	-26	18
PIPR	*	*	*	-12	*	*	*	-27	*	*	*	*	35	*	7	23	-25	*
AMBR	*	*	*	*	31	*	-100	*	*	*	*	*	18	*	-7	58	*	*
PRGN	-15	19	92	33	-69	47	79	-80	-27	36	-10	65	2	-67	-40	3	-4	-63
CRWN	5	-13	-30	-27	-1	-10	36	-30	5	-22	66	10	11	1	11	-4	-8	*
DELL	-28	*	*	*	*	*	*	6	*	24	*	*	-1	*	*	-39	*	38
IVRY	26	-12	7	-13	-71	11	72	14	-11	-48	61	21	2	0	8	-23	-44	*
RAVN	*	*	*	*	54	*	-52	*	*	*	*	*	13	*	20	-12	*	-23
RECD	2	*	*	12	-25	*	24	4	*	*	*	*	-13	*	10	-55	42	*
SNTP	-93	-19	-88	86	24	74	-58	56	32	5	-33	-16	17	1	3	14	52	-57
LNCR	4	3	29	-15	28	-39	10	0	-4	-43	-4	19	-29	18	24	-7	6	*
HO48	*	*	*	*	41	*	-24	*	*	*	*	*	22	*	-24	-15	*	*
4771	*	*	*	*	33	*	5	*	*	*	*	*	8	*	-33	-14	*	*
Rainfall cms.	39			42				37			29			27				

See Table 9 for site codes and Table 61 for variety abbreviations.

Residual mean square of the table 4.6 times the plot error.

Sites are ordered by region, with the lowest yielding sites to the left of each group.

Table 25

FITCON residuals x 10 from the 1976 NIAB potato trial data.
Variate: Total yield, t/ha.

Region	NC	NC	WC	WC	WC	WC	SW	SW	EC	EC	EC	EC	EE	EE	EE	EE	EE	EE
Site code	13	2	3	20	7	6	8	12	23	4	29	28	25	5	9	1	19	10
CARA	*	-47	-55	-75	1	-57	136	*	-47	-19	73	-27	152	36	-13	-12	-59	15
CLDA	*	3	13	*	3	-174	20	*	*	-27	*	*	*	53	28	74	*	6
CORE	*	-15	44	*	30	-37	67	*	*	32	*	*	87	20	-21	-65	-63	-80
CRFT	13	5	41	-13	89	89	-47	30	-23	-20	-35	-13	-46	-31	-8	-38	-3	9
DSIR	37	13	3	-31	-2	11	-85	-16	-33	8	-1	19	-36	67	0	29	9	7
DYTN	48	20	18	-12	-101	-58	65	22	29	4	1	26	-42	-22	-32	-29	63	-1
EDWD	-41	31	7	-65	-94	-59	-62	-1	39	27	17	65	-28	-54	30	5	103	82
ESTM	21	85	77	68	-60	93	-83	9	42	45	-30	-4	-57	-46	19	-70	-57	-53
GRAC	*	*	0	*	*	47	*	*	*	29	*	*	*	*	4	-44	*	-37
MJST	*	50	*	14	*	*	*	*	*	*	-2	-23	-40	*	*	*	*	*
PIPR	*	*	*	*	*	49	-48	*	*	*	*	*	76	-25	-13	-40	*	*
CRWN	39	-70	-9	36	52	32	6	-4	10	-11	-5	-20	-60	49	3	39	-69	-18
RECD	*	33	13	*	-17	30	-50	*	*	31	*	*	*	-26	-41	2	*	25
STRA	*	41	-4	*	41	-62	2	*	*	23	*	*	*	-46	51	-28	*	-18
DH21	-117	-67	-85	87	75	60	35	-26	-18	-77	21	-15	-41	2	17	98	45	5
1225	*	-6	-21	-11	6	49	-42	0	*	-10	-56	-15	-7	11	2	41	31	27
9164	*	-76	-41	2	-22	-14	86	-16	*	-36	17	5	41	11	-27	39	*	30
Rainfall cms.	27		29				10			18				10				

See Table 9 for site codes and Table 61 for variety abbreviations.

Residual mean square of the table 5.5 times the plot error.

Sites are ordered by region, with the lowest yielding sites appearing to the left of each group.

Table 26

Regression analysis: mean yield (t/ha) and Beta parameter (t/ha), from modified joint regression analysis for each year.

NIAB potato data.

Variate: total yield.

Year	CARA Mean adj.	CARA $\hat{\beta}_i$	DÉSIRÉE Mean adj.	DÉSIRÉE $\hat{\beta}_i$	DRAYTON Mean adj.	DRAYTON $\hat{\beta}_i$	KING EDWARD Mean adj.	KING EDWARD $\hat{\beta}_i$
1976	40.7	0.835±0.112	38.7	0.985±0.101	31.0	0.937±0.101	31.0	1.039±0.101
1975	44.7	0.339±0.102*	42.1	1.090±0.100	39.6	0.892±0.100	40.9	1.056±0.100
1978			54.5	1.187±0.147				
1974			54.0	1.200±0.142	51.0	0.707±0.168	56.7	0.752±0.152
1977	46.4	0.387±0.210*	47.2	1.030±0.117			45.0	0.708±0.116*
1970							40.5	0.904±0.070
1972			45.8	1.064±0.070			44.5	0.745±0.070*
1971			51.4	0.987±0.161			49.4	1.074±0.146
1969							38.2	0.724±0.178
1973	50.7	0.247±0.279+	52.0	1.200±0.160	48.9	0.092±0.279*	48.8	1.184±0.160

Year	ESTIMA Mean adj	ESTIMA $\hat{\beta}_i$	MAJESTIC Mean adj	MAJESTIC $\hat{\beta}_i$	MARIS PIPER Mean adj	MARIS PIPER $\hat{\beta}_i$	OAKPARK AMBER Mean adj	OAKPARK AMBER $\hat{\beta}_i$
1976	31.8	0.888±0.122	32.9	1.051±0.288	34.0	0.970±0.256		
1975	41.5	1.099±0.102	42.6	0.878±0.100				
1978								
1974	59.2	1.365±0.151*	56.8	0.918±0.138	55.9	0.547±0.288		
1977	44.1	1.373±0.213			44.5	1.108±0.223		
1970			44.2	0.890±0.070				
1972			47.2	0.961±0.071	48.6	0.953±0.111		
1971			49.4	1.074±0.146				
1969			41.5	0.845±0.154				
1973	62.4	1.928±0.279*	51.8	0.885±0.160	56.1	0.991±0.321	48.7	0.211±0.282+

Table 26 cont.

Year	PARAGON Mean Adj	PARAGON $\hat{\beta}_i$	PENTLAND CROWN Mean adj	PENTLAND CROWN $\hat{\beta}_i$	PENTLAND DELL Mean adj	PENTLAND DELL $\hat{\beta}_i$	PENTLAND HAWK Mean adj	PENTLAND HAWK $\hat{\beta}_i$
1976			42.6	1.012±0.106				
1975	45.6	1.490±0.123*	47.6	1.103±0.100				
1978			57.2	1.130±0.100				
1974	58.7	1.118±0.152	60.1	0.999±0.149				
1977			49.3	1.106±0.116	42.5	1.212±0.335	43.5	1.442±0.306
1970			43.7	1.259±0.149				
1972	46.2	0.980±0.122	48.5	1.129±0.070+				
1971			51.5	1.306±0.168+				
1969							40.8	1.136±0.154
1973	58.3	1.221±0.160	55.6	0.937±0.161	50.1	1.482±0.327		

Year	PENTLAND IVORY Mean Adj	PENTLAND IVORY $\hat{\beta}_i$	PENTLAND RAVEN Mean Adj	PENTLAND RAVEN $\hat{\beta}_i$	PENTLAND SQUIRE Mean Adj	PENTLAND SQUIRE $\hat{\beta}_i$	RECORD Mean Adj	RECORD $\hat{\beta}_i$
1976							29.0	1.004±0.146
1975			38.2	1.162±0.223			40.8	0.976±0.201
1978	50.9	0.920±0.155					45.4	0.884±0.214
1974			51.6	1.194±0.150			48.1	0.928±0.168
1977							37.1	1.112±0.170
1970	39.8	1.089±0.148			45.8	0.893±0.129		
1972	44.4	1.028±0.070			45.9	1.353±0.123*	40.3	0.890±0.190
1971	52.4	0.260±0.198*			54.6	0.466±0.244+	46.9	0.857±0.330
1969	37.9	0.942±0.154						
1973	45.8	1.026±0.161	44.9	0.459±0.279			48.7	1.064±0.221

Table 26 cont.

Year	STORMONT ENTERPRISE Mean Adj	$\hat{\beta}_i$	ULSTER LANCER Mean Adj	$\hat{\beta}_i$	447/1 Mean Adj	$\hat{\beta}_i$	HO/48 Mean Adj	$\hat{\beta}_i$
1976								
1975	46.5	0.723±0.212			40.6	1.028±0.102	33.6	1.032±0.123
1978								
1974	56.0	0.810±0.198	51.6	1.027±0.179	55.7	1.030±0.151	47.9	1.036±0.145
1977								
1970	44.7	0.865±0.070+	40.2	1.107±0.129				
1972	44.4	0.928±0.070	42.9	1.160±0.070*			40.2	0.748±0.109*
1971	51.4	1.074±0.296	46.0	0.710±0.146+			45.5	0.792±0.224*
1969	44.4	1.075±0.154						
1973	50.4	1.005±0.160	48.7	0.891±0.161	49.0	0.981±0.282	45.9	0.798±0.282

Year	CLADA Mean Adj	$\hat{\beta}_i$	CORRIE Mean Adj	$\hat{\beta}_i$	CROFT Mean Adj	$\hat{\beta}_i$	GRACIA Mean Adj	$\hat{\beta}_i$
1976	31.3	0.754±0.146	36.8	0.647±0.127*	35.7	1.161±0.101	38.4	0.895±0.168
1975			38.5	0.772±0.201	41.3	1.197±0.100+		
1978								
1974					61.2	1.101±0.223		
1977	35.4	0.932±0.222			48.8	1.651±0.223+	49.1	1.311±0.138*

Year	MONITOR Mean Adj	$\hat{\beta}_i$	SPLENDOR Mean ADJ	$\hat{\beta}_i$	STRATH Mean Adj	$\hat{\beta}_i$	1225A3 Mean Adj	$\hat{\beta}_i$
1976	41.3	1.131±0.201			29.2	0.860±0.146	36.5	1.148±0.111
1975			39.2	1.066±0.201	35.2	0.736±0.321		
1978								
1974			47.6	0.914±0.168				
1977					41.7	0.650±0.149*	44.9	1.214±0.117+

Table 26 conc.

Year	431B3 Mean Adj	431B3 $\hat{\beta}_i$	916/4 Mean Adj	916/4 $\hat{\beta}_i$	DHS/21 Mean Adj	DHS/21 $\hat{\beta}_i$
1976			39.7	1.063±0.121	40.4	1.351±0.101*
1975					44.9	0.515±0.321
1978			58.9	0.609±0.215		
1974						
1977	40.0	0.847±0.117	47.1	1.005±0.117	46.8	0.737±0.117*

Year	PATRONES Mean Adj	PATRONES $\hat{\beta}_i$	SPARTAAN Mean Adj	SPARTAAN $\hat{\beta}_i$	ULSTER BREVET Mean Adj	ULSTER BREVET $\hat{\beta}_i$
1970	45.7	1.417±0.152*	48.6	1.348±0.152+	42.3	0.776±0.070*
1972						
1971					44.9	0.825±0.232
1969	42.6	1.015±0.154	45.6	1.160±0.154	40.6	0.926±0.154
1973						

Year	S62471 Mean Adj	S62471 $\hat{\beta}_i$	694/3 Mean Adj	694/3 $\hat{\beta}_i$
1970	44.8	1.390±0.072*	37.8	0.647±0.129+
1972	45.0	1.143±0.070+	44.1	0.7738±0.19*
1971	50.3	1.468±0.159*	48.6	0.934±0.224
1969	43.2	1.232±0.239		
1973				

Notes:

* indicates a significant difference from 1.00 at the 5% level.

\+ indicates a significant difference from 1.00 at the 10% level.

The mean yields are adjusted to allow for the environments at which the variety did not appear.

Each estimated value of $\hat{\beta}_i$ is calculated from a minimum of five observations.

Table 27

Estimates of $\hat{\beta}_i$ from AUGFITCON made for seven varieties at the same ten centres for three years. Varieties VI-V7 considered.

Year	1974 $\hat{\beta}_i$	1975 $\hat{\beta}_i$	1976 $\hat{\beta}_i$
VI	1.037±0.212	1.138±0.167	1.255±0.144
V2	1.200±0.180	1.023±0.167	0.974±0.144
V3	0.621±0.180+	0.901±0.167	0.781±0.144
V4	0.658±0.180	0.894±0.167	0.972±0.167
V5	1.493±0.180*	1.122±0.167	0.866±0.144
V6	1.078±0.180	1.001±0.174	1.080±0.144
V7	0.866±0.178	0.926±0.167	1.070±0.144

Table 28

Estimates of $\hat{\beta}_i$ from AUGFITCON made for seven varieties (the same seven varieties that appear in Table 27 when ten varieties are grown at the same ten sites each year.

Year	1974 $\hat{\beta}_i$	1975 $\hat{\beta}_i$	1976 $\hat{\beta}_i$
VI	1.098±0.222	1.165±0.170	1.301±0.174
V2	1.275±0.179	1.034±0.170	1.014±0.174
V3	0.656±0.176+	0.900±0.170	0.858±0.174
V4	0.703±0.176	0.877±0.170	1.010±0.174
V5	1.565±0.176*	1.138±0.179	0.830±0.174
V6	1.132±0.176	1.022±0.179	1.173±0.174
V7	0.928±0.176	0.903±0.170	1.104±0.174

Table 29

Estimates of $\hat{\beta}_i$ from AUGFITCON made for seven varieties (the same seven varieties that appear in Table 27 and 28) when they are grown at 14 sites, ten of which are identical to the sites used in Tables 27 and 28.

Year	1975 $\hat{\beta}_i$	1976 $\hat{\beta}_i$
VI	1.117±0.084	1.171±0.105
V2	1.002±0.084	1.003±0.105
V3	0.848±0.084+	0.939±0.105
V4	1.009±0.084	1.055±0.105
V5	0.983±0.086	0.836±0.105
V6	1.058±0.084	0.954±0.105
V7	0.925±0.163	1.074±0.140

+ indicates significance from 1.00 at the 10% level.
* indicates significance from 1.00 at the 5% level.

Table 30

Regession analysis: mean yield (t/ha) and sensitivity parameter (t/ha), from modified joint regression analysis of NIAB potato trial data.

$\hat{\beta}_{iy}$ measures the sensitivity of the yield of variety i to differences between years.

Variety	Mean yield(adj.)	$\hat{\beta}_{iy}$
Pentland Crown^{R}	50.1	0.871±0.109
Estima	48.3	1.518±0.124*
Stormont Enterprise^{R5}	47.6	0.715±0.146+
Désirée^{R}	47.4	0.781±0.113
Maris Piper^{R5}	47.4	1.128±0.127
Majestic^{R}	46.4	1.034±0.112
King Edward^{R}	44.2	1.042±0.104
Pentland Ivory^{R}	43.7	0.871±0.156
Ulster Lancer^{5}	43.2	0.858±0.195
Drayton	42.5	0.983±0.130
Record^{R5}	40.9	0.938±0.113
HO/48^{5}	39.0	1.109±0.200

Notes:

Each variety appears in at least five of the 10 years.

5 indicates that the variety appears only five times.

R indicates that the variety appears on the Recommended List.

* indicates that $\hat{\beta}_{iy}$ is signficantly different from 1.00 at the 5% level.

+ indicates that $\hat{\beta}_{iy}$ is significantly different from 1.00 at the 10% level.

Table 31

Yield sensitivity parameters (β_i) estimated from trial* and agricultural** data.

Variety	Mean yields Trials (S)	Trials	Agric (S)	Yield sensitivity parameters Trials (S) $\bar{\beta}_i$	Trials $\hat{\hat{\beta}}_i$	Trials $\hat{\beta}_{iy}$	Agric (S) $\hat{\beta}_i$
Majestic	-1.4	-0.5	-4.4	0.832	0.904	1.030	0.917
King Edward	-1.9	-2.7	-1.4	1.030	0.887	1.040	1.376
Pentland Crown	3.3	3.2	5.7	1.186	1.106	0.871	0.699
Mean yield t/ha	38.9	46.9	35.9				

* Trial data from NIAB.
** Agricultural data from PMB.
(S) Figures taken from Table 5 of Simmonds (1980)

$\bar{\beta}_i$ are mean regressions of each variety on Majestic, King Edward, Pentland Crown and Pentland Dell.
$\hat{\hat{\beta}}_i$ are the median regressions estimated in Table 26 for each variety.
$\hat{\beta}_{iy}$ are regressions estimated over years, from Table 30.

Simmonds' trial data cover the period 1962-1974, c.f. 1969-1978 trial data used in this thesis. Agricultural data cover the period 1969-1977.

Table 32

Estimates of the variety sensitivities from AUGFITCON and a SVD of a subset from the 1975 data of NIAB potato trials, variate: total yield, t/ha.

Variety	AUGFITCON estimates	Characteristic vector of first singular value
Cara	0.481894779	0.122136953
Corrie	0.827815708	0.209811128
Croft	0.807892929	0.204761672
Désirée	1.200383490	0.304238990
Drayton	0.800536882	0.202897272
King Edward	0.938698879	0.237914643
Estima	0.973129118	0.246641031
Majestic	1.113610070	0.282246135
Monitor	1.144750350	0.290138684
Oakpark	1.114588457	0.282493162
Amber		
Pentland	1.12508002	0.317017182
Crown		
Pentland	1.107410780	0.280674920
Raven		
Record	1.009517580	0.255863745
Splendor	1.119719550	0.283794597
477/1	1.109254960	0.281142337

Common ratio between pairs of estimates = 3.945529

Table 33

Effect of different regression estimates, used to complete incomplete data sets, on the latent roots of the completed data set.

Data set	Estimate of λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
Complete data	4132.6461	367.8354	173.9004	60.1020	38.5402	0.0
Method of completion	λ_1	λ_2	λ_3	λ_4	λ_5	λ_6
FITCON	3976.0563	383.4156	141.7052	55.3759	40.2108	0.0
AUGFITCON	3938.6921	363.2074	142.1818	47.7854	30.8414	0.0
Extended AUGFITCON	3973.1591	369.6775	138.4388	47.6514	31.8164	0.0

Data used was a subset of the 1975 NIAB potato trial data, six varieties were considered at ten centres. 10% of the entries were deleted in the incomplete analyses.
FITCON is described by Patterson(1979).
AUGFITCON is described by Digby(1979).
Extended AUGFITCON is described in chapter 6.

Table 34

The percentage of the variation accounted by each principal component of the completed variety x centre data sets of potato yields from NIAB trials.

Variety means removed from the data, variate: total yield.

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
λ_1	75.9	96.5	81.7	94.0	81.7	82.5	90.0	89.3	89.5	89.9
λ_2	9.5	1.4	7.2	1.8	7.3	6.6	2.6	4.0	3.4	4.7
λ_3	5.1	0.8	4.3	1.2	3.5	2.9	2.2	2.4	2.2	3.4
λ_4	4.3	0.6	2.7	1.0	2.8	2.0	1.4	1.5	1.3	2.0
λ_5	1.8	0.2	1.7	0.7	1.6	1.8	1.1	0.8	1.0	0.0
λ_6	1.8	0.1	0.9	0.4	0.9	1.3	0.6	0.7	0.8	
λ_7	0.9	0.1	0.6	0.3	0.8	1.0	0.5	0.6	0.6	
λ_8	0.7	0.1	0.3	0.3	0.5	0.7	0.4	0.2	0.4	
λ_9	0.0	0.0	0.2	0.1	0.4	0.6	0.3	0.2	0.3	
λ_{10}		0.0	0.2	0.1	0.3	0.3	0.2	0.1	0.1	
λ_{11}		0.0	0.1	0.1	0.2	0.1	0.2	0.1	0.1	
λ_{12}		0.0	0.0	0.0	0.1	0.1	0.2	0.1	0.1	
λ_{13}			0.0	0.0	0.0	0.1	0.1	0.1	0.1	
λ_{14}				0.0	0.0	0.0	0.0	0.0	0.0	
λ_{15}					0.0	0.0	0.0	0.0	0.0	
λ_{16}					0.0	0.0	0.0	0.0	0.0	
λ_{17}					0.0	0.0	0.0	0.0	0.0	
λ_{18}					0.0		0.0			
λ_{19}							0.0			

Table 35

Variety adjusted mean yields from NIAB potato trials in the English regions, 1969-1978.
Variate: total yield, t/ha.

Variety	Region EE	EC	NC	WC	SW
BRVT	44	42	43	45	49
CARA	46	48	44	48	51
CLDA	40	41	44	42	49
CORE	42	44	44	47	50
CRFT	43	46	45	53	51
DSIR	45	45	46	49	50
DYTN	42	42	43	44	48
EDWD	42	44	43	44	49
ESTM	43	46	46	55	48
GRCA	44	45	48	53	49
MJST	43	45	46	48	49
PIPR	45	46	45	51	49
MNTR	42	42	42	48	50
AMBR	43	43	44	47	50
PRGN	46	48	51	54	51
PATN	43	45	46	49	50
CRWN	47	50	47	53	52
DELL	41	41	44	46	50
HAWK	43	41	44	47	49
IVRY	40	41	43	45	48
RAVN	38	39	44	45	49
SQIR	45	46	45	51	50
RECD	39	40	41	44	49
SNTP	45	45	43	50	52
SPTN	44	46	47	51	51
SPDN	40	40	42	44	49
STRA	40	42	45	43	49
LNCR	40	43	43	46	48
DH21	46	47	44	52	52
HO48	38	39	42	44	47
S624	41	47	48	52	49
1225	44	42	45	50	50
43B3	43	41	43	47	52
4771	42	43	43	49	50
6943	42	43	46	46	49
9164	48	47	44	49	51

See Table 61 for abbreviations.

Table 36

Variety mean (adjusted) yields (total yield, t/ha) at English and Scottish regions from potato trial data. (English data from NIAB trials, Scottish data from The Scottish Colleges' trials.)

	English Regions					Scottish regions		
Variety	EE	EC	NC	WC	SW	ES	WS	NS
CRFT	43	46	45	53	51	46	46	44
DSIR	45	45	46	49	50	44	47	44
DYTN	42	42	43	44	48	46	39	29
ESTM	43	46	46	55	48	52	46	48
PIPR	45	46	45	51	49	46	42	44
PRGN	46	48	51	54	51	50	52	45
CRWN	47	50	47	53	52	49	44	44
DELL	41	41	44	46	50	43	47	40
IVRY	40	41	43	45	48	45	44	41
SQIR	45	46	45	51	50	46	49	44
RECD	39	40	41	44	49	43	43	38
SNTP	45	45	43	50	52	47	44	38
STRA	40	42	45	43	49	39	36	42
LNCR	40	43	43	46	48	41	45	39

Notes: See Table 61 for region and variety abbreviations.
Yields from English regions are based on data from 1969-1978
Yields from Scottish regions are based on data from 1971-1978

Table 37

Mean total yield (adjusted) at each eastern and western region during 1971-1977, expressed as a percentage of the yield of Pentland Crown.
Variate: total yield
Data: NIAB maincrop potato trials.

Variety	Environment									
	SW76	EE776	EE72	EC77	EE75	EC74	EC76	EE77	EE74	EC72
CROFT	86	116		106	74		76		110	
DÉSIRÉE	85	103	91	95	85	78	94	95	117	92
DRAYTON	86	95			75		73		105	
ESTIMA	72	105			82	98	75	80	119	94
M.PIPER		121	98					91		
PARAGON			90			92				
P.CROWN	100	100	100	100	100	100	100	100	100	100
P.DELL										
P.IVORY			89			81				90
P.SQUIRE			99							
RECORD	66	99	82		74			76	90	78
SNTPRS			95		96	92		96	100	89
U.LANCER										90
rainfall (cms.)	10	10	14	16	17	18	18	20	21	23
Yield of P.CROWN (t/ha)	51	34	46	50	44	60	33	47	48	52

Variety	Environment									
	SW75	WC74	EE73	WC75	EC75	SW71	WC76	EC73	EC71	EE71
CROFT	90	110		92	93		92			
DÉSIRÉE	86	95	94	87	89	107	89	87	92	107
DRAYTON	77	84	94	92	91		65			
ESTIMA	75	104	110	93	96		83			
M.PIPER		91	110			108				
PARAGON	87	94	99		100			103		
P.CROWN	100	100	100	100	100	100	100	100	100	100
P.DELL									81	
P.IVORY		85	79			102		82	81	101
P.SQUIRE						97			92	104
RECORD		81	87	87					80	94
SNTPRS		88	90	104		100	70	83	93	104
STRATH				77					83	
U.LANCER		86	89				67	82		96
Rainfall (cms.)	23	26	27	27	28	28	29	29	31	31
Yield of P.CROWN (t/ha)	58	62	53	47	47	41	50	57	59	50

Table 37

Variety	Environment							
	SW77	SW72	WC71	SW74	SW73	WC77	WC73	WC72
CROFT								
DÉSIRÉE	98	94	88	92	96	97	95	98
DRAYTON							79	
ESTIMA	88			96			124	
M.PIPER						94		107
PARAGON				95	103		109	102
P.CROWN	100	100	100	100	100	100	100	100
P.DELL	92				97			
P.IVORY		115	87	82	84		82	94
P.SQUIRE		119	96					105
RECORD			85			77	88	90
SNTPRS		158	98	98	99		96	89
STRATH					89	80		
U.LANCER		90					87	98
Rainfall (cms.)	32	34	36	35	37	39	42	45
Yield of P.CROWN (t/ha.)	54	46	58	58	62	50	56	55

Notes: SW75 is the abbreviation used for the South West region in 1975, and similar conventions are used for the other headings.

See Table 61 for the region abbreviations.

SNTPRS is the abbreviation for Stormont Enterprise.

Table 38

Summary of the rainfall, in ems., during the growing season (April - August) in each NIAB region.

Data taken from the Monthly Weather Sheets issued by the Met.Office.

Year	1969				1970			
Region	Min	Max	Median	Total	Min	Max	Median	Total
SW	4	13	7	42	2	9	8	30
EE	3	8	6	28	2	5	3	19
WC	6	13	6	39	3	12	8	41
EC	3	8	4	29	2	6	5	20
NC	5	9	6	33	3	11	6	34

Year	1971				1972			
Region	Min	Max	Median	Total	Min	Max	Median	Total
SW	2	10	4	28	3	12	6	34
EE	3	9	6	31	1	4	3	14
WC	5	10	7	36	6	11	11	45
EC	3	11	5	31	2	6	6	23
NC	4	10	7	37	5	11	10	41

Year	1973				1974			
Region	Min	Max	Median	Total	Min	Max	Median	Total
SW	6	9	8	37	2	14	6	35
EE	4	7	6	27	1	7	4	22
WC	7	10	8	42	2	9	5	26
EC	3	8	6	29	1	9	2	18
NC	5	9	8	39	2	9	7	29

Year	1975				1976			
Region	Min	Max	Median	Total	Min	Max	Median	Total
SW	0.5	7	5	23	0.4	4	2	10
EE	1	6	3	17	1	4	2	10
WC	4	8	5	28	3	11	4	29
EC	3	7	6	28	2	8	3	18
NC	4	9	6	33	2	12	4	27

Year	1977				1978			
Region	Min	Max	Median	Total	Min	Max	Median	Total
SW	4	11	6	32	1	8	4	22
EE	1	10	4	20	4	6	5	28
WC	3	11	9	39	2	9	4	38
EC	1	6	4	16	3	9	5	32
NC	3	8	8	31	3	10	5	29

See Table 61 for abbreviations.

Table 39

Adjusted mean variety yields expressed as a percentage of the yield of Pentland Crown.
Variate: total yield. NIAB potato trial data 1969-1978.

	Region					Soil type		
Variety	EC	EE	NC	SW	WC	2	3	4
BREVET	84	94	91	96	85+	91	93	94
CARA	97	97	94	99	91	97	94	95
CLADA	83	85	92	95	80+	89	83	85
CORRIE	88	90	94	96	89	92	90	88
CROFT	93	92	95	98	100	96	96	97
DÉSIRÉE	90	95	96	87	94	96	94	95
DRAYTON	85	88	90	94	83+	88	86	88
K.EDWARD	88	94	91	94	84	87	90	91
ESTIMA	92	91	98	94	104+	94	98	90
GRACIA	90	93	102	96	100+	96	99	94
MAJESTIC	91	92	97	96	91	94	94	93
M.PIPER	92	96	94	96	97	92	98	92
MONITOR	84	89	89	97	92+	88	94	89
O.AMBER	87	91	93	96	88	90	93	90
PARAGON	96	98	108	98	103+	100	103	97
PATRONES	91	89	96	97	93	91	95	90
P.CROWN*	100	100	100	100	100	100	100	100*
P.DELL	83	87	93	96	87+	87	90	93
P.HAWK	83	91	93	95	88+	90	95	88
P.IVORY	83	86	91	93	86+	87	88	95
P.RAVEN	78	81	94	96	86+	88	86	83
P.SQUIRE	92	96	96	97	98	93	100	93
RECORD	80	83	87	94	83+	84	84	85
SNTPRS	89	96	91	100	95+	91	96	96
SPARTAAN	92	93	100	99	97	95	99	96
SPLEND	80	84	89	96	84+	84	87	89
STRATH	85	85	94	99	82+	89	86	90
U.LANCER	86	86	91	93	87+	89	88	86
DHS/21	94	97	92	100	99	93	102	101
HO/48	78	81	88	92	84+	84	83	84
S62471	94	86	102	95	98+	96	96	84+
1225A3	85	93	95	97	94+	93	96	94
431B3	83	90	90	92	89	88	91	85
477/1	86	91	92	96	92	89	92	94
694/3	86	89	96	95	88	91	89	91
916/4	95	101	94	99	94	94	102	98
Yield of P.CROWN	50	47	47	52	53	48	49	53
Mean yield of all varieties	44	43	45	50	48	44	45	48

Notes to Table 39:
The yields are given in t/ha.
* indicates the control variety.
+ the percentage yield of control varies by more than 10%.
SNTPRS is the abbreviation used for Stormont Enterpise.
For other variety abbreviations see Table 61.

Table 40

Adjusted variety mean yields expressed as a percentage of the yield of Pentland Crown. Total weight of tubers (t/ha) recorded in NIAB potato trials.

	Year								
	1970	1971	1972	1973	1974	1975	1976	1977	1978
Variety									
CARA	*	*	*	90	*	93	97	99	*
CRFT	*	*	*	*	102	86	85	103	*
DSIR	*	98	94	93	90	88	94	96	94
DYTN	*	*	*	86	84	83	74	*	*
EDWD	94	88	92	88	94	86	74	91	86
ESTM	*	*	*	113	98	87	76	87	*
MJST	102	95	97	93	95	89	78	*	*
PIPR	*	*	101	101	96	*	81	89	*
PRGN	*	*	95	105	98	100	*	*	*
CRWN	100	100	100	100	100	100	100	100	100
IVRY	91	97	92	82	85	*	*	*	*
RECD	*	89	84	88	79	86	69	76	80
RAVN	*	*	*	80	86	79	*	*	*
SQIR	107	103	102	*	*	*	*	*	*
SNTP	103	100	92	90	93	99	*	*	*
STRA	*	*	*	*	*	76	70	85	*
BRVT	98	89	*	*	*	*	*	*	*
LNCR	91	88	88	88	86	*	*	*	*
DH21	*	*	*	*	*	99	96	95	*
HO48	*	86	85	82	80	71	*	*	*
S624	104	98	93	*	*	*	*	*	*
4771	*	*	*	88	93	85	*	*	*
6943	91	92	92	*	*	*	*	*	*
9164	*	*	*	*	*	*	94	96	103
Rainfall, cms.	144	163	157	174	130	129	93	138	130
No. of varieties yielding ⩾ Pentland Crown	4	2	2	3	1	1	0	1	1

See Table 61 for variety abbreviations.

Table 41

Variety mean yields (adjusted) for maincrop potato varieties from NIAB trial data.
Variate: total yield, t/ha.

	Year									
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
CARA	*	*	*	*	50	*	44	41	49	*
CRFT	*	*	*	*	*	61	41	36	51	*
DSIR	*	*	51	46	52	54	42	40	47	54
DYTN	*	*	*	*	48	51	40	31	*	*
EDWD	38	40	46	44	49	56	41	31	45	50
ESTM	*	*	*	*	63	59	42	32	43	*
MJST	41	44	49	47	52	57	43	33	*	*
PIPR	*	*	*	49	56	58	*	34	44	*
PRGN	*	*	*	46	58	59	47	*	*	*
CRWN	*	43	52	48	56	60	48	42	49	57
IVRY	38	39	51	44	46	51	*	*	*	*
RECD	*	*	46	41	49	47	41	29	37	45
RAVN	*	*	*	*	44	51	38	*	*	*
SQIR	*	46	53	50	*	*	*	*	*	*
SNTP	44	45	52	44	50	56	47	*	*	*
STRA	*	*	*	*	*	*	36	29	42	*
BRVT	41	42	46	*	*	*	*	*	*	*
LNCR	*	39	46	43	49	51	*	*	*	*
DH21	*	*	*	*	*	*	47	40	47	*
HO48	*	*	45	41	46	48	34	*	*	*
S624	43	45	51	45	*	*	*	*	*	*
4771	*	*	*	*	49	56	41	*	*	*
6943	*	39	48	45	*	*	*	*	*	*
9164	*	*	*	*	*	*	*	40	47	59
Rainfall cms	170	144	163	157	174	130	129	93	138	130

See Table 61 for variety abbreviations.

Table 42

Residuals from fitting an additive model to the table of variety x year yields of potato varieties in NIAB potato trials, Table 41.
Variate: total yield in t/ha.

	Year										
	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978	RMS
CARA	*	*	*	*	-4.5	*	-0.6	3.6	1.6	*	9.0
CRFT	*	*	*	*	*	2.8	-4.2	-1.8	3.2	*	9.7
DSIR	*	*	0.1	-1.0	-1.1	-2.7	-1.4	4.0	1.6	0.4	3.8
DYTN	*	*	*	*	-0.0	-1.2	1.0	0.2	*	*	0.6
EDWD	-1.2	-0.1	-2.1	0.8	-1.2	2.8	0.5	-1.6	2.6	-0.5	2.6
ESTM	*	*	*	*	9.1	1.6	-2.7	-4.7	-3.3	*	25.1
MJST	-0.5	1.3	-0.8	1.3	-0.4	1.0	0.0	-2.1	*	*	1.2
PIPR	*	*	*	1.5	2.5	0.4	*	-2.0	-2.3	*	3.6
PRGN	*	*	*	-3.3	2.5	-0.6	1.3	*	*	*	4.8
CRWN	*	-3.4	-2.0	-1.1	-0.2	0.5	1.3	3.5	0.8	0.6	3.6
IVRY	-0.8	-0.2	4.2	1.7	-3.1	-1.8	*	*	*	*	5.7
RECD	*	*	1.6	0.1	2.0	-2.9	3.8	-0.4	-2.1	-2.0	4.7
RAVN	*	*	*	*	-2.2	1.3	0.8	*	*	*	2.4
SQIR	*	-0.1	-0.2	0.3	*	*	*	*	*	*	0.05
SNTP	1.5	0.8	0.6	-2.5	-2.9	-0.8	3.4	*	*	*	4.3
STRA	*	*	*	*	*	*	-1.3	-0.7	2.0	*	2.1
BRVT	0.7	1.4	-2.1	*	*	*	*	*	*	*	2.3
LNCR	*	0.2	-0.5	0.7	0.3	-0.8	*	*	*	*	0.3
DH21	*	*	*	*	*	*	0.5	1.5	-2.0	*	2.2
HO48	*	*	1.2	1.9	0.5	-1.3	-2.3	*	*	*	2.4
S624	0.3	1.3	-0.0	-1.6	*	*	*	*	*	*	1.1
4771	*	*	*	*	-1.3	1.5	-0.3	*	*	*	1.3
6943	*	-1.3	0.1	1.2	*	*	*	*	*	*	1.0
9164	*	*	*	*	*	*	*	0.5	-2.0	1.5	2.2
RMS	0.9	1.9	2.8	2.4	9.2	3.0	4.1	6.2	5.0	1.4	

Notes: For variety abbreviations see Table 61.
RMS, Residual mean square.

Table 43

Mean yields of Estima and Pentland Crown in west central sites during 1973-1977 recorded in NIAB potato trials.

Yields are total weight of tubers measured in t/ha.

Year	Estima	Pentland Crown
1973	91.0	68.6
	54.9	53.5
1974	43.8	46.8
	97.0	81.1
	68.1	54.2
	61.7	55.4
1975	28.1	28.8
	45.5	48.2
	55.0	59.1
	45.1	51.2
1976	29.3	31.0
	54.1	58.3
	36.4	57.9
	47.2	54.3
1977	50.4	42.7
	92.9	73.5
	63.6	57.2

Table 44

Residuals arising from the analysis by an additive model of Table 35.

	Region					
	EE	EC	NC	WC	SW	RSS
BRVT	2.4	-0.8	-0.2	-2.1	0.7	11.5
CARA	1.2	2.7	-1.8	-1.8	-0.3	15.5
CLDA	-0.0	0.1	1.6	-3.4	1.7	16.9
CORE	-0.1	0.2	0.1	-0.8	0.5	0.9
CRFT	-1.4	0.9	-1.3	2.7	-0.8	12.1
DSIR	0.8	0.1	-0.1	0.0	-0.8	1.2
DYTN	0.9	0.5	0.3	-2.3	0.6	6.6
EDWD	1.1	1.3	-0.2	-2.5	0.2	9.3
ESTM	-1.9	0.2	-0.0	5.0	-3.3	40.0
GRCA	-0.8	-0.8	1.6	2.9	-2.8	20.5
MJST	0.0	1.0	0.8	-0.8	-1.0	3.2
PIPR	1.1	0.6	-1.3	1.3	-1.7	8.0
MNTR	0.1	-0.9	-1.6	1.2	1.2	6.2
AMBR	0.4	0.1	-0.1	-1.0	0.6	1.6
PRGN	-0.8	-0.2	2.2	2.2	-3.3	20.9
PATN	-0.9	0.6	0.3	0.3	-0.3	1.4
CRWN	0.4	2.1	-1.1	0.7	-2.0	10.2
DELL	-0.3	-1.2	0.9	-0.9	1.5	5.6
HAWK	1.0	-1.5	0.6	-0.6	0.5	4.1
IVRY	-0.2	-0.4	0.5	-0.5	0.6	1.0
RAVN	-2.1	-2.4	2.5	-0.3	2.2	21.0
SQIR	0.7	0.2	-1.0	1.6	-1.4	6.0
RECD	-0.3	-0.7	-0.2	-1.0	2.2	6.6
SNTP	1.2	-0.3	-2.7	1.0	0.8	10.4
SPTN	-0.9	0.1	0.7	0.9	-0.8	2.7
SPDN	-0.4	-1.0	0.2	-1.1	2.3	8.0
STRA	-0.7	0.6	2.0	-3.0	1.1	15.0
LNCR	-0.7	0.9	0.3	-0.7	0.2	2.0
DH21	0.7	0.8	-3.0	1.7	-0.1	13.2
HO48	-0.7	-1.3	0.9	-0.2	1.4	4.9
S624	-3.6	1.4	2.2	2.0	-2.0	31.0
1225	0.8	-1.9	-0.0	1.2	-0.0	5.6
43B3	0.5	-1.6	-1.3	-0.4	2.7	11.6
4771	0.2	-0.6	-0.7	0.9	0.3	1.8
6943	-0.3	-0.1	1.7	-1.2	-0.1	4.6
9164	2.8	1.3	-2.4	-1.0	-0.7	16.4
RSS	51.9	41.0	67.4	111.3	81.1	

SE = 1.4

Notes: the standard error (SE) can be used to compare deviations of the residuals from zero.
RSS : residual sum of squares.
See Table 61 for abbreviations.

Table 45

Mean (adjusted) total yields,t/ha, expressed as a percentage of the yield of Pentland Crown from potato trials in England and Scotland. English data come from NIAB trials performed between 1969-1978. Scottish data come from trials performed between 1971-1978.

	England					Scotland		
Region	EC	EE	SW	WC	NC	ES	WS	NS
Yield of P.CROWN (t/ha)	43.8	42.7	49.6	48.1	44.6	48.7	44.5	44.1
% Variety yields								
P.CROWN	100	100	100	100	100	100	100	100
CROFT	93	92	98	100	95	95	104	100
DÉSIRÉE	90	95	97	94	96	91	106	99
DRAYTON	85	88	94	83	90	94	87	67
ESTIMA	92	91	94	104	98	107	103	108
M.PIPER	92	96	96	97	94	95	94	99
P.DELL	83	87	96	87	93	89	106	91
P.IVORY	83	86	93	86	91	93	100	94
P.SQUIRE	92	96	97	98	96	94	110	101
PARAGON	96	98	98	103	98	103	117	102
STOR.ENT.	89	96	110	95	91	96	98	87
STRATH	85	85	99	82	94	80	82	96
RECORD	80	83	94	83	87	89	96	86
U.LANCER	86	86	93	87	91	84	101	88
No of varieties with yields $\geqslant$ 100%	0	0	1	3	0	2	8	4

Notes: For abbreviations see Table 61.

Table 46

Residuals arising from fitting an additive model to Table 36.

	English Regions					Scottish Regions			
	EE	EC	NC	WC	SW	ES	WS	NS	RSS
CRFT	-1.4	0.6	-1.2	2.2	-0.5	-0.8	0.1	1.1	10.7
DSIR	0.8	-0.2	-0.1	-0.5	-0.5	-2.2	1.6	1.1	9.8
DYTN	2.3	1.6	1.7	-1.4	2.4	3.9	-2.2	-8.3	107.4
ESTM	-3.0	-1.2	-1.0	3.5	-4.0	3.8	-1.5	3.4	67.9
PIPR	1.6	0.8	-0.8	1.3	-0.8	0.0	-3.5	1.4	20.4
PRGN	-1.3	-1.0	1.8	1.2	-3.3	0.3	3.2	-0.8	29.2
CRWN	1.1	2.5	-0.4	0.9	-0.9	0.2	-3.1	-0.3	19.0
DELL	-0.7	-2.0	0.5	-1.9	1.5	-1.1	3.8	-0.2	26.3
IVRY	-1.0	-1.5	-0.2	-1.8	0.2	1.4	1.5	1.5	13.0
SQIR	0.4	-0.4	-1.2	0.8	-1.3	-1.7	2.4	1.1	14.0
RECD	-0.5	-1.3	-0.5	-1.8	2.3	1.0	1.3	-0.3	13.5
SNTP	2.0	0.1	-1.9	1.2	1.9	1.1	-1.1	-3.2	25.3
STRA	0.3	1.2	3.0	-2.5	2.5	-3.4	-5.0	4.0	75.6
LNCR	-0.5	0.8	0.5	-1.0	0.7	-2.5	2.5	-0.5	15.4
RSS	27.4	22.5	24.2	42.7	54.2	61.3	98.4	115.6	

SE = 1.8

Notes:

The standard error (SE) can be used to compare deviations of the residuals from zero.
RSS is the residual sum of squares.
See Table 61 for abbreviations.

Table 47

Correlations between fifteen varieties tested in the 1975 NIAB potato trials, estimated from a complete subset of the variety x centre table. Variate measured total yield, t/ha.

CARA	1.00														
CORE	0.75	1.00													
CRFT	0.54	0.84	1.00												
DSIR	0.54	0.88	0.80	1.00											
DYTN	0.75	0.90	0.81	0.77	1.00										
EDWD	0.75	0.85	0.82	0.79	0.87	1.00									
ESTM	0.63	0.85	0.80	0.74	0.92	0.88	1.00								
MJST	0.81	0.79	0.79	0.64	0.89	0.94	0.89	1.00							
MNTR	0.32	0.71	0.94	0.82	0.63	0.71	0.66	0.62	1.00						
AMBR	0.67	0.89	0.99	0.82	0.86	0.88	0.84	0.87	0.89	1.00					
CRWN	0.59	0.90	0.80	0.96	0.78	0.70	0.70	0.60	0.77	0.89	1.00				
RAVN	0.68	0.91	0.93	0.87	0.83	0.83	0.74	0.76	0.87	0.95	0.88	1.00			
RECD	0.65	0.87	0.89	0.83	0.78	0.95	0.78	0.83	0.83	0.92	0.75	0.90	1.00		
SPDN	0.62	0.97	0.91	0.89	0.89	0.88	0.87	0.79	0.81	0.93	0.88	0.91	0.91	1.00	
4771	0.78	0.91	0.84	0.88	0.93	0.96	0.88	0.92	0.73	0.90	0.84	0.88	0.90	0.91	1.00
	CARA	CORE	CRFT	DESR	DYTN	ESTA	ESTM	MJST	MNTR	AMBR	CRWN	RAVN	RECD	SPDN	4771

See Table 6I for variety abbreviations.

Table 48

Correlations between fifteen varieties tested in the 1975 NIAB potato trials, estimated from the entire data matrix with missing values estimated by AUGFITCON estimates.

CARA	1.00														
CORE	0.49	1.00													
CRFT	0.45	0.90	1.00												
DSIR	0.38	0.92	0.88	1.00											
DYTN	0.49	0.90	0.90	0.84	1.00										
EDWD	0.40	0.83	0.89	0.81	0.93	1.00									
ESTM	0.48	0.90	0.88	0.91	0.90	0.84	1.00								
MJST	0.39	0.81	0.83	0.81	0.92	9.94	0.90	1.00							
MNTR	0.35	0.89	0.94	0.93	0.87	0.84	0.88	0.83	1.00						
AMBR	0.44	0.93	0.97	0.93	0.93	0.90	0.93	0.91	0.97	1.00					
CRWN	0.44	0.95	0.87	0.96	0.86	0.80	0.86	0.80	0.93	0.92	1.00				
RAVN	0.44	0.93	0.96	0.95	0.92	0.90	0.91	0.89	0.96	0.99	0.93	1.00			
RECD	0.44	0.92	0.95	0.92	0.90	0.93	0.91	0.90	0.93	0.97	0.89	0.97	1.00		
SPDN	0.41	0.91	0.95	0.94	0.92	0.90	0.93	0.90	0.94	0.97	0.92	0.97	0.96	1.00	
4771	0.39	0.91	0.91	0.88	0.92	0.91	0.86	0.88	0.89	0.94	0.91	0.93	0.93	0.94	1.00
	CARA	CORE	CRFT	DSIR	DYTN	EDWD	ESTM	MJST	MNTR	AMBR	CRWN	RAVN	RECD	SPDN	4771

See Table 61 for variety abbreviations.

Table 49

Correlations between nine sites, used in the 1975 NIAB potato trials, calculated from a complete subset of the total yield data matrix.

Site code									
1	1.00								
2	-0.09	1.00							
3	-0.07	0.61	1.00						
4	0.52	0.46	0.33	1.00					
5	0.34	0.24	0.09	0.13	1.00				
6	0.35	-0.11	0.06	0.48	0.19	1.00			
7	0.42	0.22	0.02	0.40	0.33	0.28	1.00		
8	0.04	-0.26	-0.15	-0.07	0.43	0.45	-0.15	1.00	
10	-0.04	0.77	0.35	0.44	0.56	0.02	0.15	0.10	1.00
	1	2	3	4	5	6	7	8	10

Correlations between nine sites, used in the 1975 NIAB potato trials, calculated from the completed total yield data matrix; AUGFITCON estimates used.

Site code									
1	1.00								
2	0.23	1.00							
3	0.24	0.50	1.00						
4	0.62	0.50	0.57	1.00					
5	0.50	0.30	0.46	0.44	1.00				
6	0.58	0.29	0.28	0.60	0.36	1.00			
7	0.74	0.41	0.22	0.54	0.43	0.58	1.00		
8	0.47	0.07	0.27	0.35	0.61	0.63	0.41	1.00	
10	0.33	0.68	0.62	0.63	0.72	0.30	0.35	0.42	1.00
	1	2	3	4	5	6	7	8	10

See Table 9 for site codes.

Table 50

Correlations between pairs of sites that give two or more correlations of 0.75 or greater, during 1969-1977.
(Correlations with Cambridge omitted.)

Site pair	1969	1970	1971	1972	1973	1974	1975	1976	1977
Morley & Sutton Bon.	0.81	-0.40	0.17	-0.37	0.84	0.33	-0.59	0.79	0.87
Myerscough &Sutton Bon.	-0.07	-0.40	0.32	-0.17	0.75	0.24	0.08	0.54	0.90
Rosemaund &Sutton Bon.	-0.04	-0.56	0.05	0.38	0.76	0.27	0.01	0.78	0.79
Durham & North Riding	0.70	0.77	0.47	-0.06	0.85	0.91	X	X	X

Table 51

Correlations between Cambridge and the sites with which it has correlations of 0.75 or more on two or more occasions between 1969-1977.

Correlations between Cambridge and,	1969	1970	1971	1972	1973	1974	1975	1976	1977
Morley	0.20	0.53	0.81	0.45	0.71	0.47	0.29	0.84	0.82
Seale Hayne	0.75	0.68	0.50	-0.11	0.06	-0.06	0.04	0.58	0.83
Sutton Bon.	0.24	0.04	0.45	-0.59	0.61	0.74	-0.55	0.76	0.88
East Riding 'A'	0.35	0.48	X	0.22	0.78	0.13	-0.09	0.85	-0.48

Notes: X indicates that the pair of sites did not appear in a year.
Sutton Bon. is the abbreviation for Sutton Bonnington.

Table 52

Correlation matrix of a subset of the varieties appearing in the 1975 NIAB potato trials.
Variate: total yield.

Variety									
CARA	1.00								
CRFT	0.46	1.00							
DSIR	0.38	0.89	1.00						
DYTN	0.51	0.90	0.83	1.00					
EDWD	0.41	0.89	0.84	0.95	1.00				
ESTM	0.48	0.88	0.91	0.90	0.85	1.00			
MJST	0.40	0.83	0.82	0.93	0.94	0.90	1.00		
CRWN	0.46	0.89	0.96	0.88	0.86	0.87	0.82	1.00	
4771	0.43	0.92	0.89	0.95	0.95	0.88	0.90	0.92	1.00
	CARA	CRFT	DSIR	DYTN	EDWD	ESTM	MJST	CRWN	4771

See Table 61 for variety abbreviations.

Table 53

Correlations between the English regions' yields arising from Table 35.
Variate: total yield of potato tubers.

EE	1.00				
EC	0.82	1.00			
NC	0.45	0.68	1.00		
WC	0.67	0.78	0.71	1.00	
SW	0.71	0.57	0.24	0.50	1.00
	EE	EC	NC	WC	SW

Table 54

Correlations between English and Scottish regions' yields arising from Table 36. Variate: total yield of potato tubers.

EE	1.00							
EC	0.89	1.00						
NC	0.69	0.80	1.00					
WC	0.80	0.88	0.75	1.00				
SW	0.79	0.67	0.47	0.57	1.00			
ES	0.63	0.65	0.58	0.83	0.33	1.00		
WS	0.46	0.42	0.59	0.64	0.39	0.49	1.00	
NS	0.45	0.60	0.65	0.72	0.32	0.39	0.52	1.00
	EE	EC	NC	WC	SW	ES	WS	NS
	English regions					Scottish regions		

See Table 61 for abbreviations.

Table 55
Classification of the NIAB recommended potato maincrop varieties.

Class	G	S	PG	PS
Variety				
	Désirée	Majestic	Croft	Stormont Enterprise
	King Edward	Record	Estima	(Pentland Squire)
	Maris Piper			
	Pentland Crown			
	Pentland Dell			
	Pentland Ivory			

G general use
S special use
P provisional recommendation

These groupings are given in the 1977/1978 Recommended List with the 1978/1979 alterations in brackets.

Table 56
Mean yields of Recommended varieties expressed as a percentage of the yield of Pentland Crown. NIAB potato trial data 1969-1978.

	Region					Soil type		
Variety	EC	EE	SW	WC	NC	2	3	4
Croft	93	92	98	100	95	96	96	97
Désirée	90	95	97	94	96	96	94	95
Estima*	92	91	94	104	98	94	98	90
King Edward*	88	90	94	84	91	87	90	91
Majestic	91	92	96	91	97	94	94	93
Maris Piper	92	96	96	97	94	92	98	92
Pentland Crown (C)	100	100	100	100	100	100	100	100
Pentland Dell*	83	87	96	87	93	87	90	93
Pentland Ivory*	83	86	93	86	91	87	88	85
Record*	80	83	94	83	87	84	84	85
Stormont Enterprise*	89	96	100	95	91	91	96	96
No.of varieties equalling or outyielding the control	0	0	1	3	0	0	0	0
Yield of the control t/ha	49.8	47.0	51.6	52.4	47.3	48.2	48.8	52.9

(C) indicates the control variety
* indicates that the percentage yield varies by 10% or more of the control yield.
See Table 61 for region abbreviations.

Table 57

Varieties which yield 90% or more of Pentland Crown's mean yield at NIAB potato trials, 1969-1978.
Variate: total yield.

11 highest yielding varieties over the EE, EC, NC, SW and WC regions.	11 highest yielding varieties over the sites on soil types classed as sandy, clay and loamy.
Cara	Cara
Croft*	Croft*
	Désirée*
Estima*	Estima*
Gracia	Gracia
Maris Piper*	
Paragon	Paragon
Pentland Crown*	Pentland Crown*
Pentland Squire	Pentland Squire
Spartaan	Spartaan
DHS64207/21	DHS64207/21
916/4	916/4

* indicates a variety appearing on the Recommended List in 1969-1978.
See Table 61 for region abbreviations.

Table 58

Estimated components of variance for recommended and non-recommended varieties of potato varieties.
NIAB trial data 1969-1978.
Variate: total yield.

For a list of the recommended varieties see Table 55, the non-recommended varieties comprise all the varieties in this study which do not appear in Table 55.

	V x Y	V x C	V x C x Y
Recommended varieties	3.8136±1.898	3.4018±1.768	12.1204±1.960
Non-recommended varieties	1.6604±2.000	3.1440±3.319	17.1485±3.187

Plot error*
18.7866

* The same plot error has been assumed for each variety group, the value estimated from the complete variety set is given.

Table 59

Environment effects of the NIAB and ADAS trial sites on maincrop potato trials, 1969-1978, from AUGFITCON analysis.

	Site Codes																		
	23	28	4	29	19	10	9	5	25	1	8	12	26	3	20	7	6	13	2	15
Region	EC				EE						SW			WC				NC		
Year																				
1969	-2	6	-6		8	-10	-6	-10		0	5		12	2	1	0	6	-6	1	-8
1973	0	-9	3		-7	3	-3	0		-6	7	9	7	12	3	-8	-3	-5	-5	2
1971	3		5		-16	-4	4	9		6	-10		-9	4	-3	7	4	5	-3	-2
1978		16	-1	5	0	-9	-2	-12	-3		2	8	-9	11	5	5	0	-6	0	
1974	-1	-1	-4		-13	1	-13	5		7	0	1	-5	-11	-1	0	17	12	8	-1
1977		14	-7	-10	6	8	-4	-11	-15	8	1	7	5	17	-8	2	-2	-2	-5	
1972	9	-1	0		0	-10	7	-10		0	-23	14	-8	1	28	0	1	4	-3	-9
1975	12	3	0	-8	4	-1	-10	-9	-3	-2	0	34	-13	-13	5	11	4	2	1	
1976	-14	4	13	-9	16	17	-4	-9	-9	5	0	15		-10	8	11	14	-14	-7	
1970	-7	6	11		-21	-4	-20	-4		3	18		9	-21	0	25	-2	7	15	-4
Median*	0.5	3.5	0	-9	0	-4	-4	-9	-9	5	0	11.5	0	1	1	2	4	2	-3	-3
Range*	28	24	23	2	39	28	25	21	12	16	41	32	24	30	36	32	19	26	21	10
SIQR*	6.4	4.9	5.3	0.6	11.6	6.8	7.6	6.6	5.8	2.8	4.7	7.9	9.8	9.2	4.6	5.7	6.0	6.0	5.0	3.6

* indicates that the 1978 environment effects were omitted in the calculations.

See Table 9 for site codes.
See Table 61 for region codes.

The years are ordered with those with the highest effects variance at the bottom of the table.
The sites are ordered, within each region, with those with the widest range of effects to the left.

Table 60

The percentage of the variation accounted by each principal component of the completed variety x centre data sets of potato yields from NIAB trials.
Environment means removed from the data, variate: total yield.

	1969	1970	1971	1972	1973	1974	1975	1976	1977	1978
ϕ_1	44.3	37.3	48.9	41.6	77.4	21.0	33.0	20.1	68.7	54.8
ϕ_2	15.7	15.5	33.6	16.6	8.6	16.3	31.2	17.0	12.0	29.8
ϕ_3	15.5	12.5	5.4	11.1	5.8	12.0	10.0	14.6	6.9	8.3
ϕ_4	11.8	10.8	4.2	8.0	2.9	11.5	7.0	11.7	3.9	7.0
ϕ_5	5.9	7.2	3.5	7.4	1.5	9.4	5.6	9.4	2.7	0.0
ϕ_6	3.2	6.0	2.1	5.6	1.1	6.6	3.7	7.0	1.4	0.0
ϕ_7	1.8	5.2	1.0	2.5	0.8	5.9	2.7	6.2	1.2	0.0
ϕ_8	1.0	2.4	0.5	2.4	0.6	4.4	2.3	5.0	1.0	0.0
ϕ_9	0.0	1.9	0.0	1.9	0.5	3.2	1.3	2.9	0.7	0.0
ϕ_{10}		1.0	0.0	1.4	0.0	2.9	1.2	2.5	0.6	0.0
ϕ_{11}		0.0	0.0	0.6	0.0	2.3	0.9	1.4	0.0	0.0
ϕ_{12}		0.0	0.0	0.6	0.0	1.7	0.0	1.2	0.0	0.0
ϕ_{13}			0.0	0.0	0.0	1.3	0.0	0.6	0.0	0.0
ϕ_{14}				0.0	0.0	0.9	0.0	0.0	0.0	0.0
ϕ_{15}					0.0	0.0	0.0	0.0	0.0	0.0
ϕ_{16}					0.0	0.0	0.0	0.0	0.0	0.0
ϕ_{17}					0.0	0.0	0.0	0.0	0.0	0.0
ϕ_{18}					0.0		0.0			0.0

Terms contributing to less than 0.5% of the variation are ignored.

Table 61

Variety codes used in graphs and variety abbreviations appearing in the tables.

Code	Variety	Abbreviation
BT	Ulster Brevet	BRVT
CA	Cara	CARA
CL	Clada	CLDA
CR	Corrie	CORE
CF	Croft	CRFT
DE	Désirée	DSIR
DY	Drayton	DYTN
ED	King Edward	EDWD
ET	Estima	ESTM
GR	Gracia	GRCA
MJ	Majestic	MJST
PI	Maris Piper	PIPR
MN	Monitor	MNTR
AM	Oakpark Amber	AMBR
PR	Paragon	PRGN
PT	Patrones	PATN
CR	Pentland Crown	CRWN
DL	Pentland Dell	DELL
HW	Pentland Hawk	HAWK
IV	Pentland Ivory	IVRY
RA	Pentland Raven	RAVN
SQ	Pentland Squire	SQIR
RE	Record	RECD
SN	Stormont Enterprise	SNTP
SP	Spartaan	SPTN
SD	Splendor	SPDN
ST	Strath	STRA
LN	Ulster Lancer	LNCR
DH	DHS64207/21	DH21 or DHS/21
HO	HO/48	HO48
S6	S647/1	S624
12	1225a3	1225
43	431B3	43B3
47	477/1	4771
69	69/43	6943
91	91/64	9164

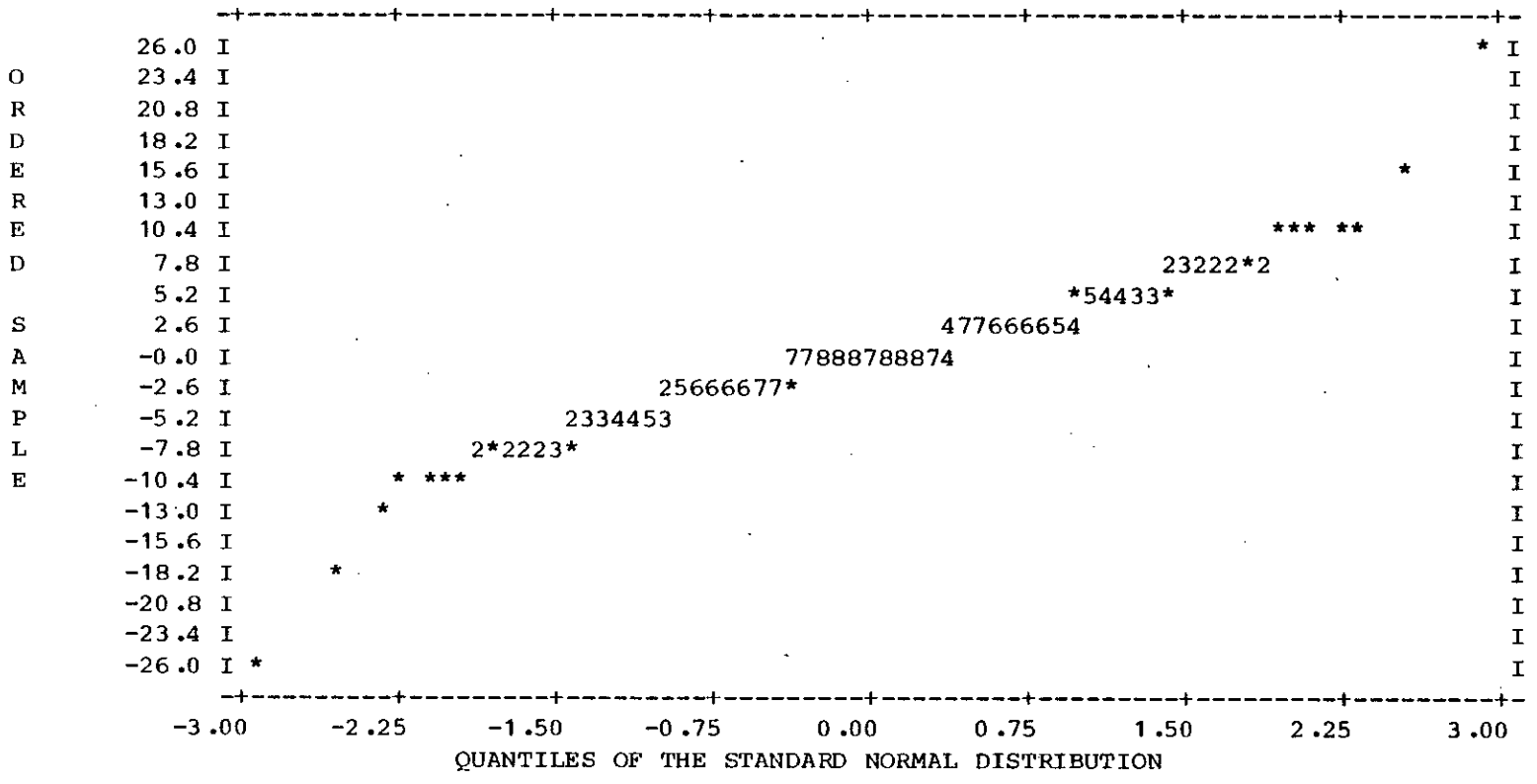
Region codes used in the Biplot graphs and other tables.

Code	Region
EE	East of England
EC	East Central (England)
NC	North Central (England)
WC	West Central (England)
SW	South West (England)
ES	East of Scotland
NS	North of Scotland
WS	West of Scotland

See Diagram L for location of English regions.

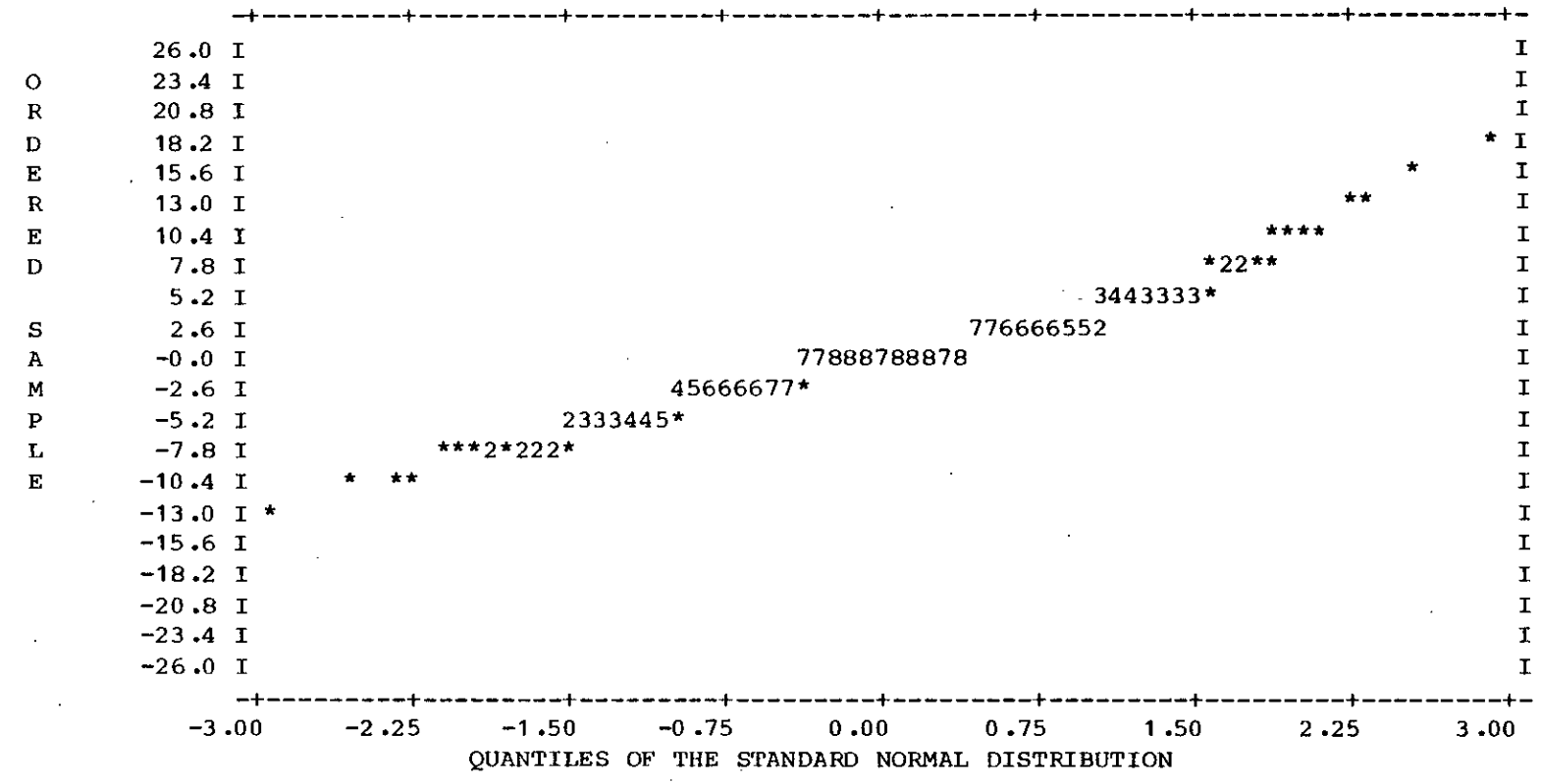
Graph 1

A graph of the FITCON residuals against the quantiles of the standard Normal distribution arising from the 1975 NIAB potato trial data. Variate: total yield



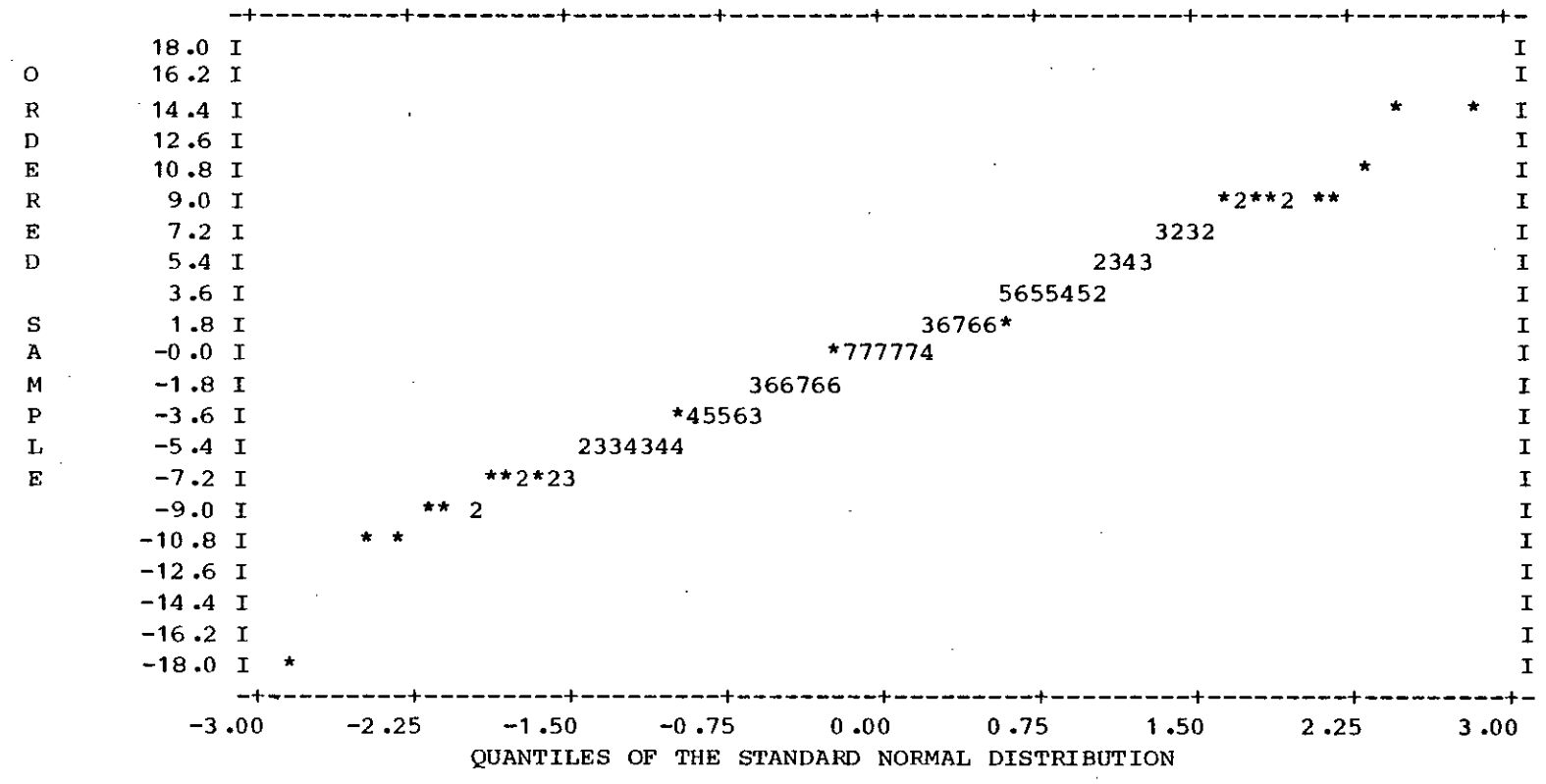
Graph 2

A graph of the AUGFITCON residuals against quantiles of the standard Normal distribution arising from the the 1975 NIAB potato trial data.



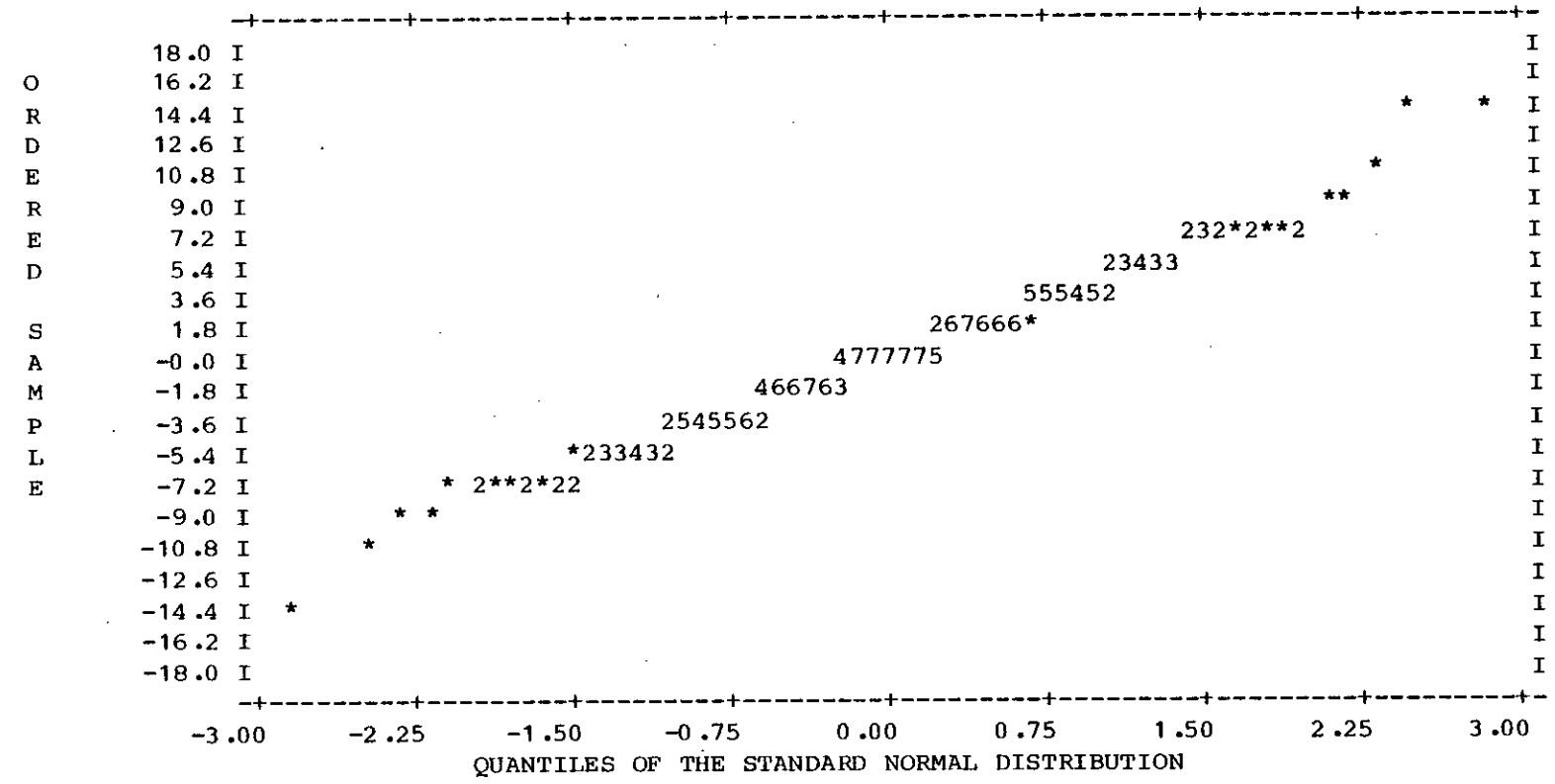
Graph 3

A graph of the FITCON residuals against the quantiles of the standard Normal distribution from the 1977 NIAB potato trial data. Variate: total yield.



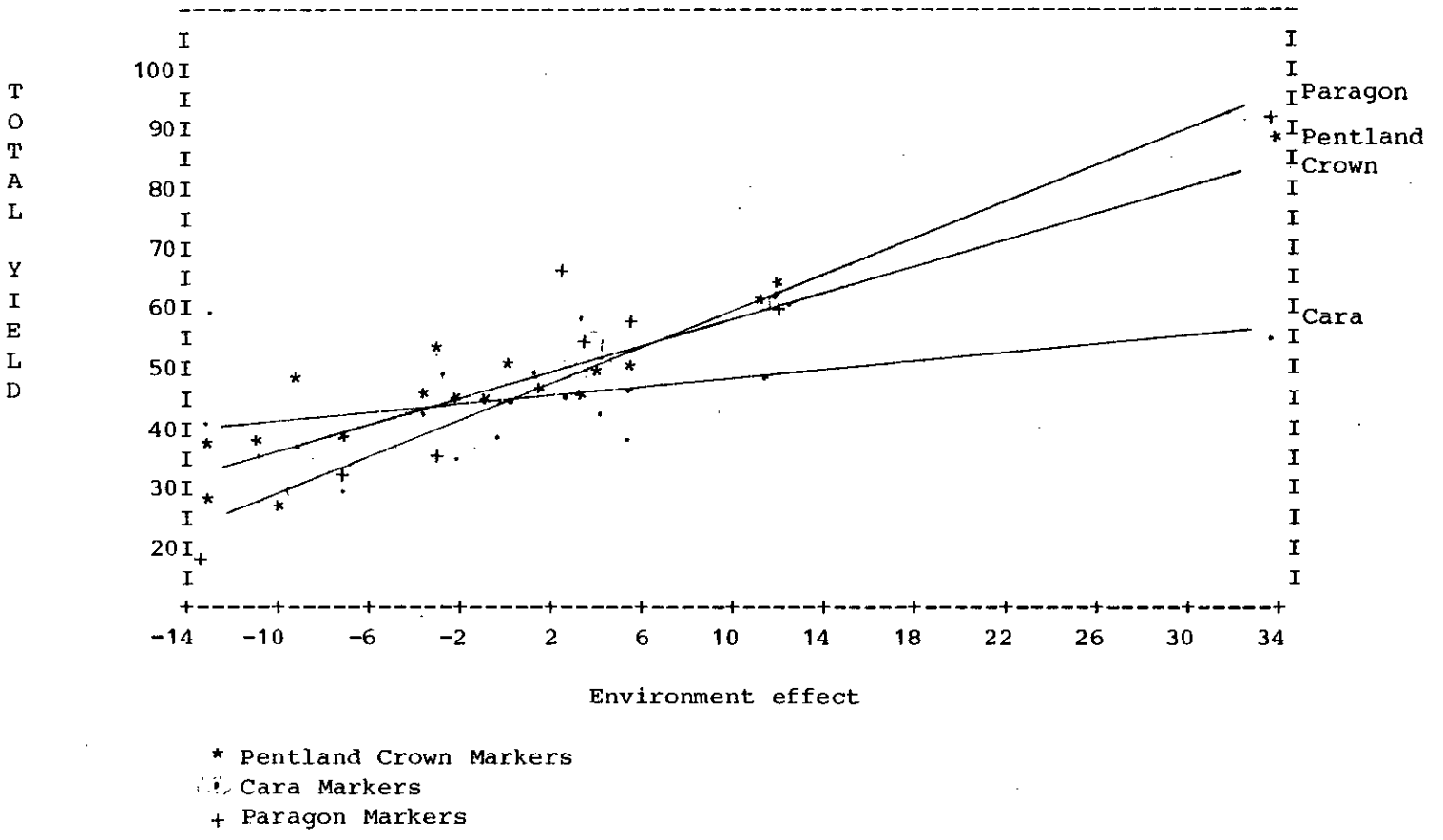
Graph 4

A graph of the AUGFITCON residuals against the quantiles of the standard Normal distribution arising from the 1977 NIAB potato trial data. Variate: total yield.



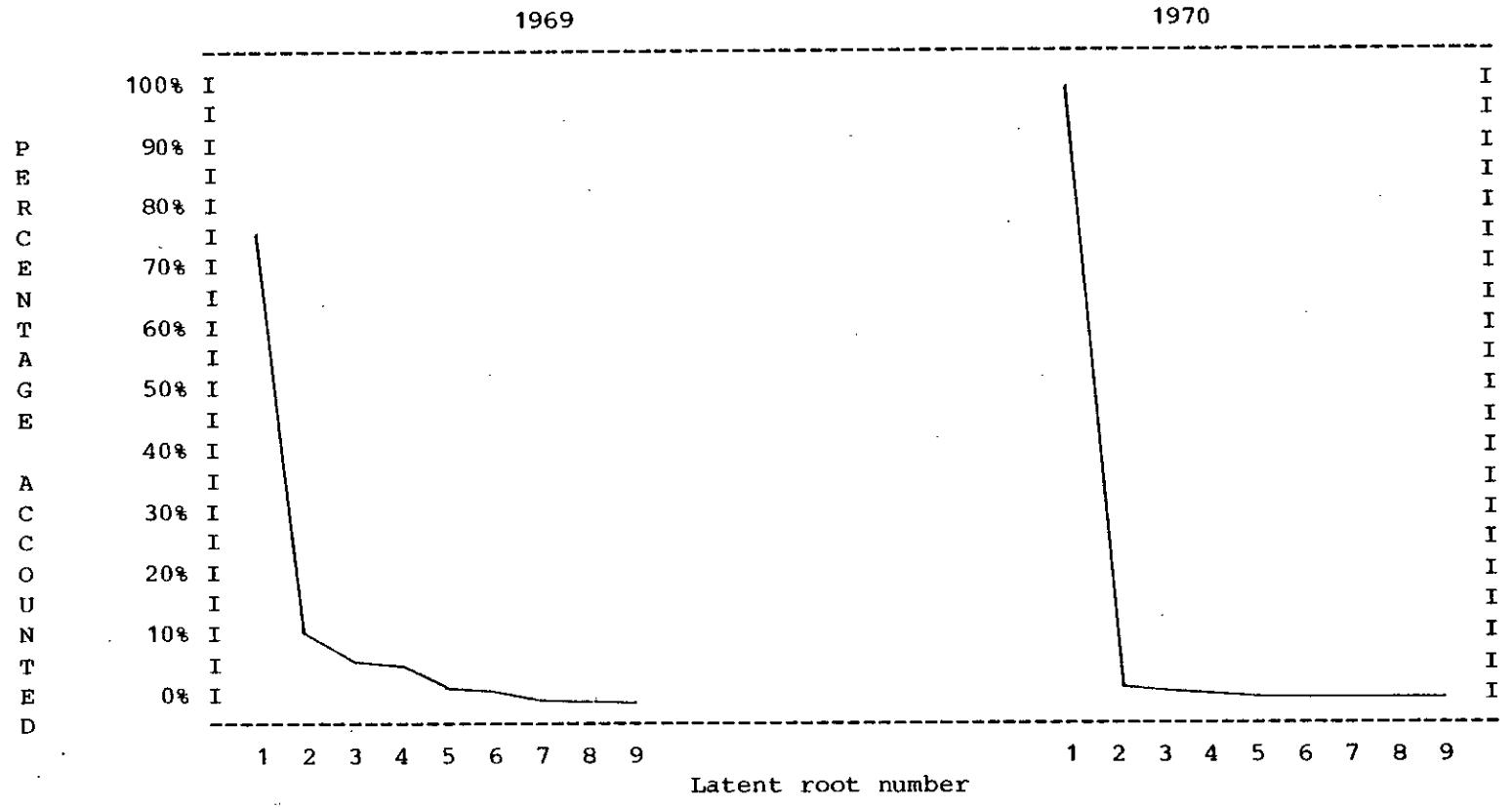
Graph 5

A graph of the total yield of tubers for three maincrop varieties at NIAB trials in 1975. Yield measured in t/ha.



Graphs 6 and 7

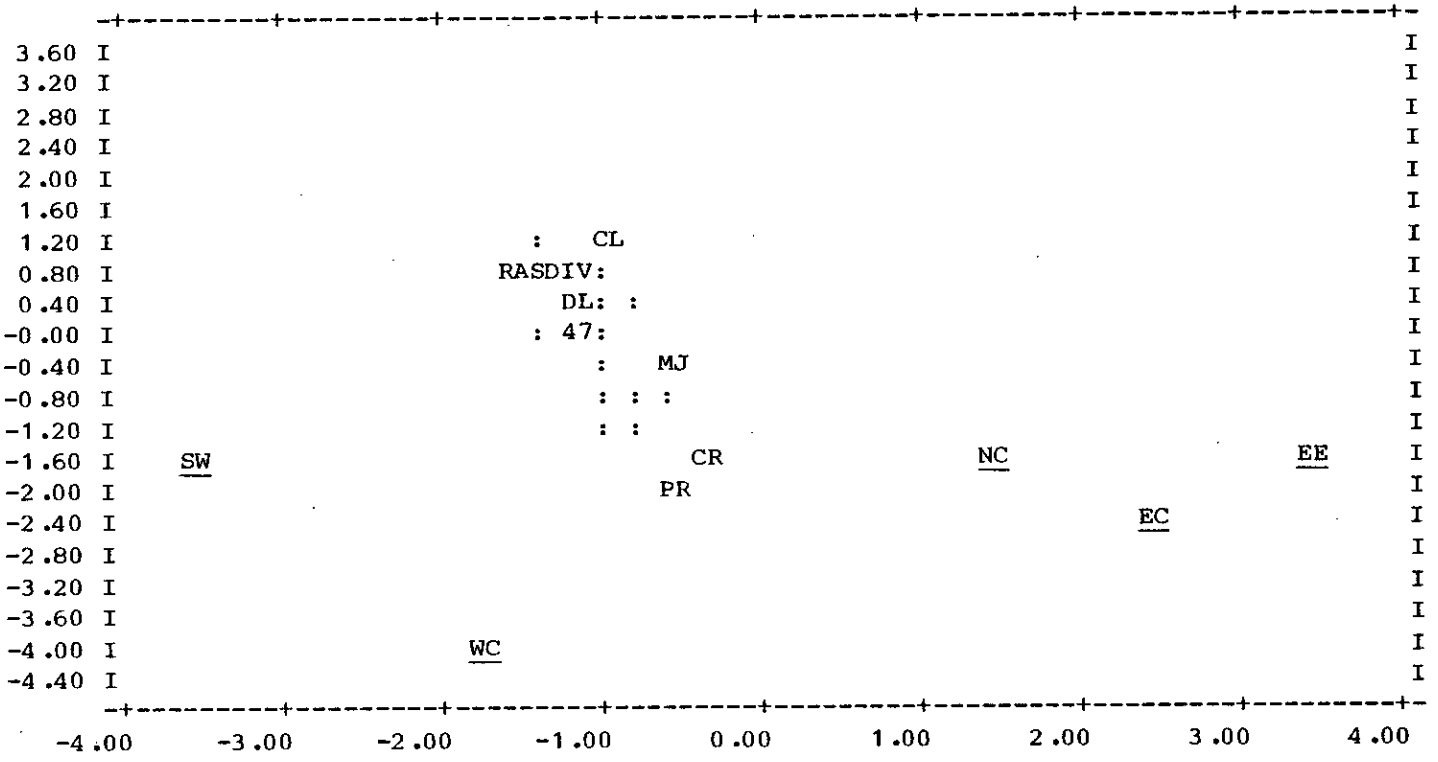
Scree graphs of the latent roots arising from the analysis of variation in 1969 and 1970 data.
Data: NIAB potato trials, variate: total yield.



All latent roots contributing less than 1.0% to the variation have been ignored.

Graph 8

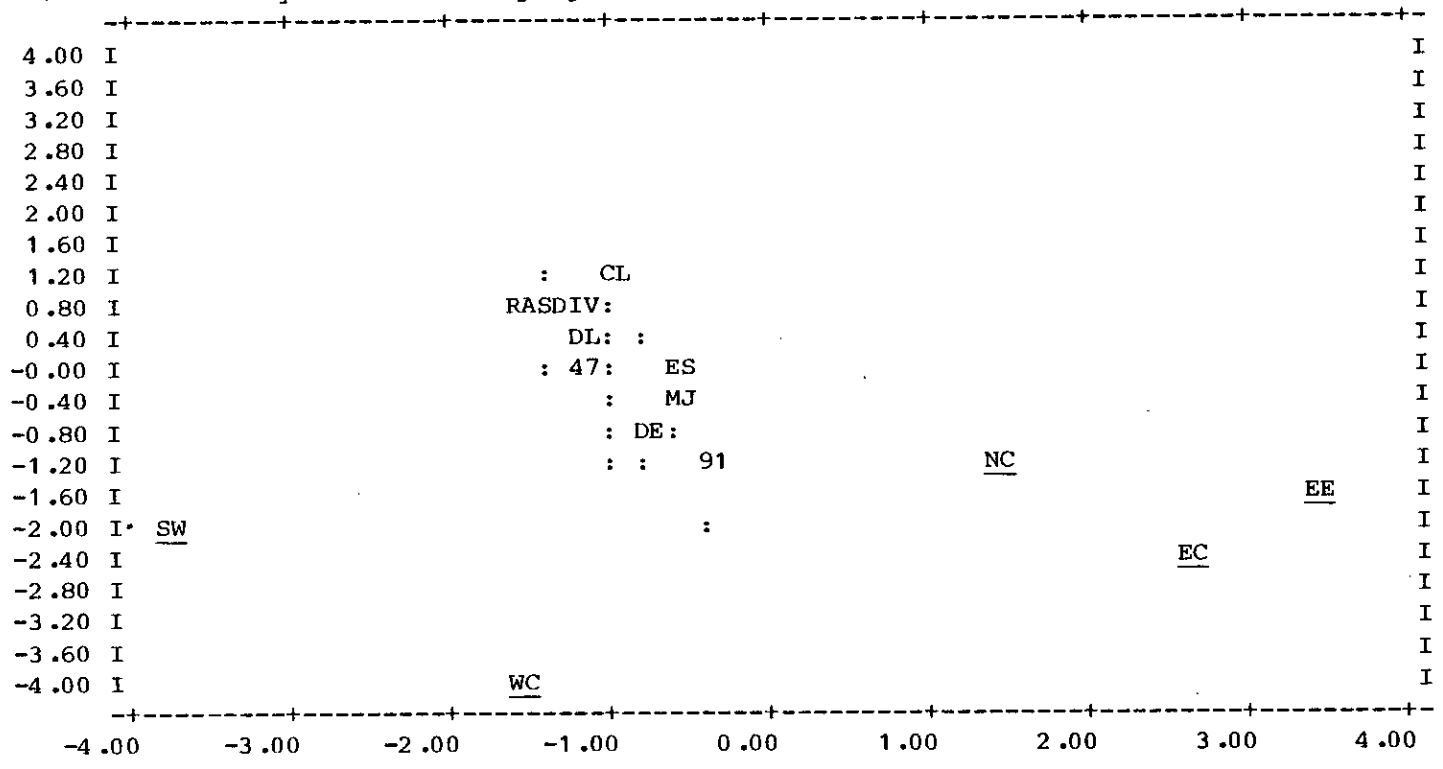
Biplot of English data (Table 35) arising from NIAB potato trials.
Variate: total yield.



See Table 61 for abbreviations.
Region markers are underlined.
: indicates two points coincident.

Graph 9

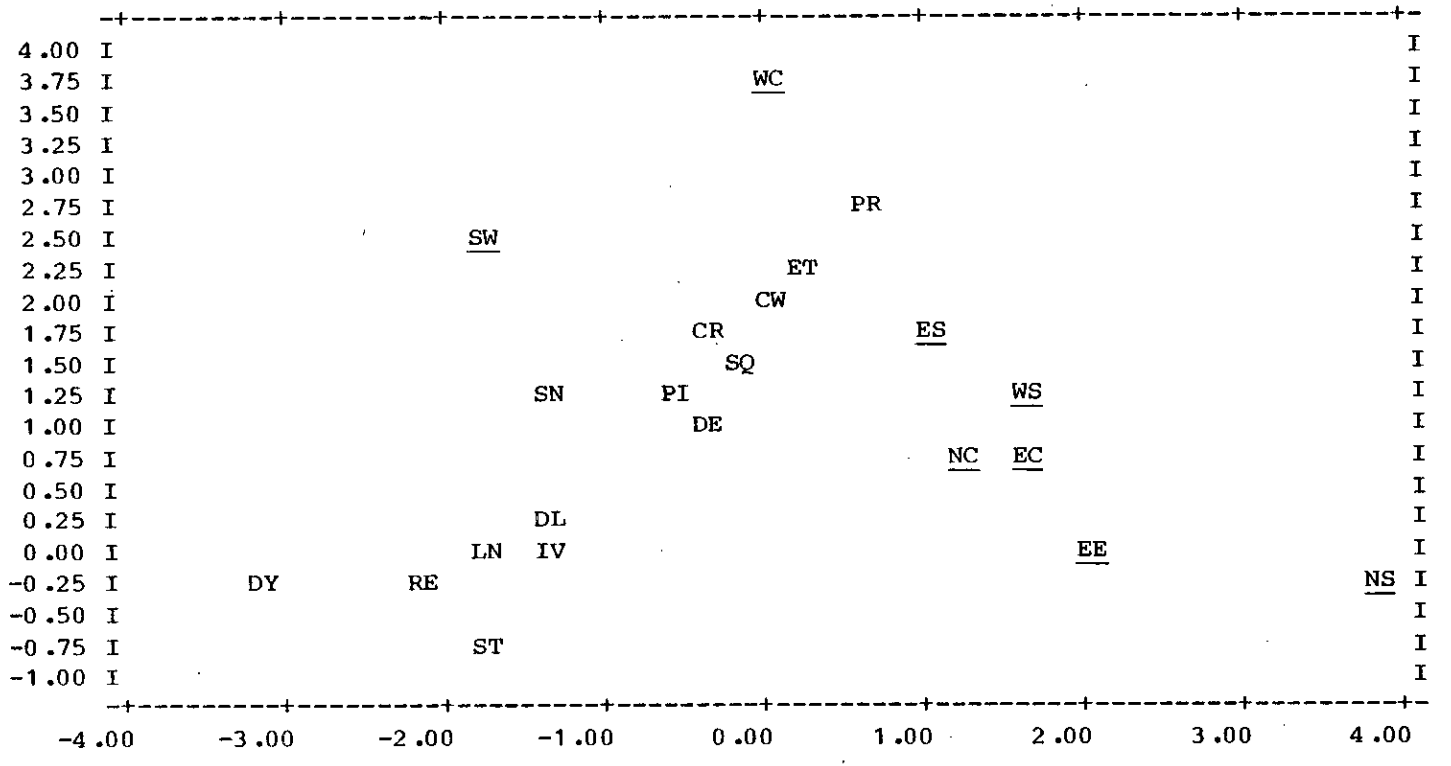
Biplot of English data (Table 35) arising from NIAB potato trials.
Variate: total yield. The outlying value of Estima at WC has been omitted.



See Table 61 for abbreviations.
Region markers are underlined.
: indicates two markers coincident.

Graph 10

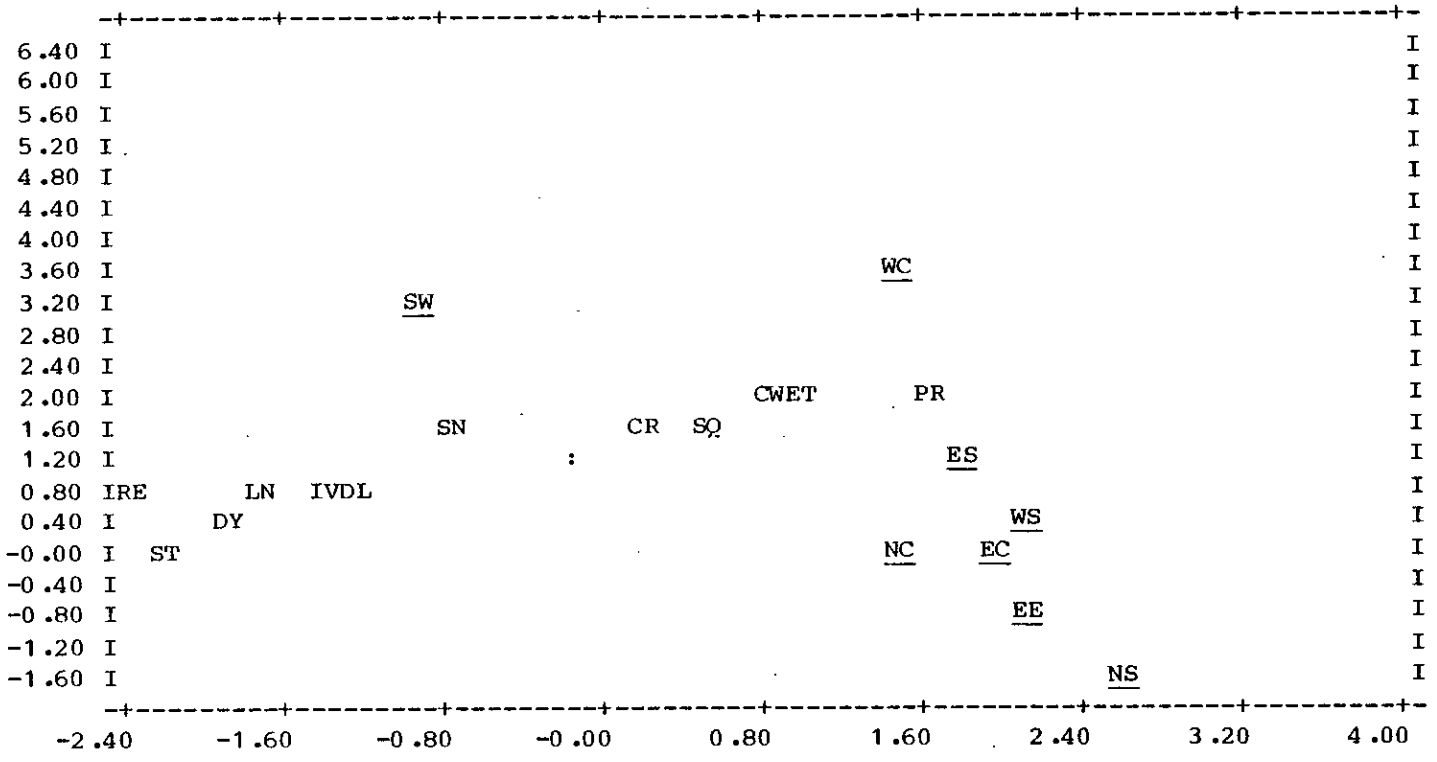
Biplot of English and Scottish variety x region data (Table 36) arising from NIAB potato trials, 1969-1978.
Variate: total yield



See Table 61 for abbreviations.
Region markers are underlined.

Graph 11

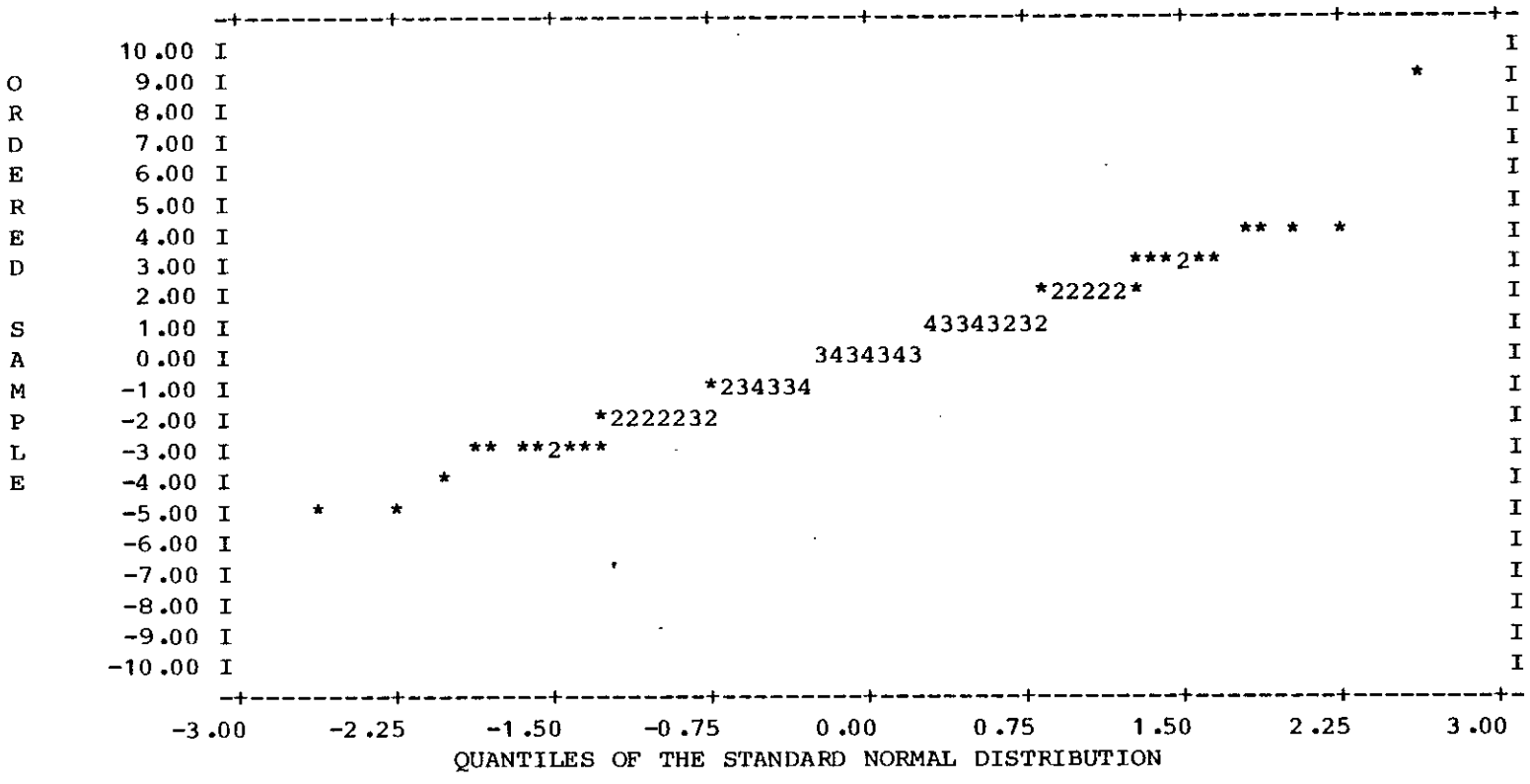
Biplot of variety x region data (Table 36) with the value of Drayton at NS replaced by its missing value estimate.
Data: NIAB potato trials, variate: total yield



See Table 61 for abbreviations.
Region markers are underlined.
: indicates two markers concident.

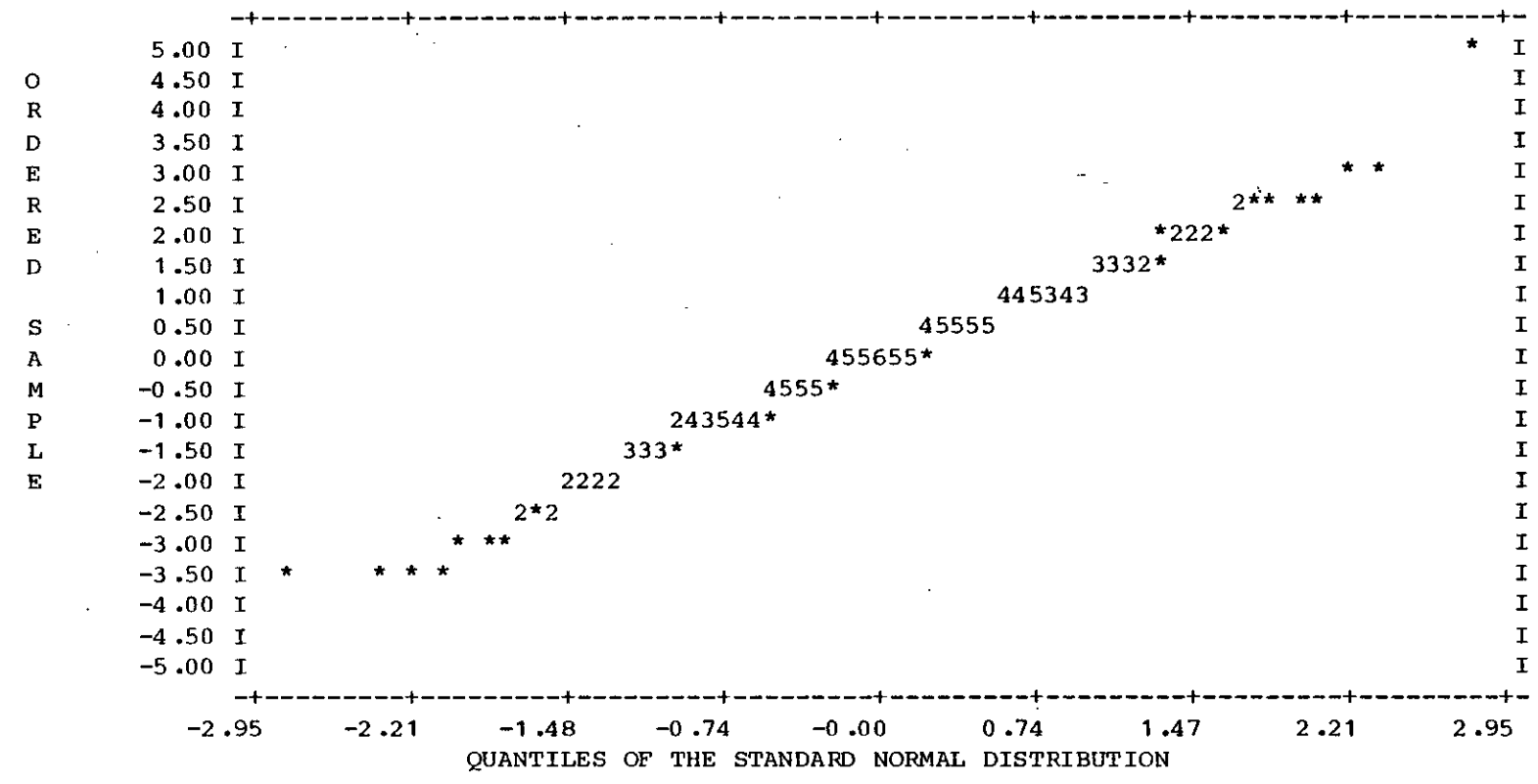
Graph 12

A graph of the residuals against quantiles of the standard Normal distribution arising from Table 41 when an additive model is fitted.
Variate: total yield
Data: NIAB maincrop potato trials, 1969-1978.



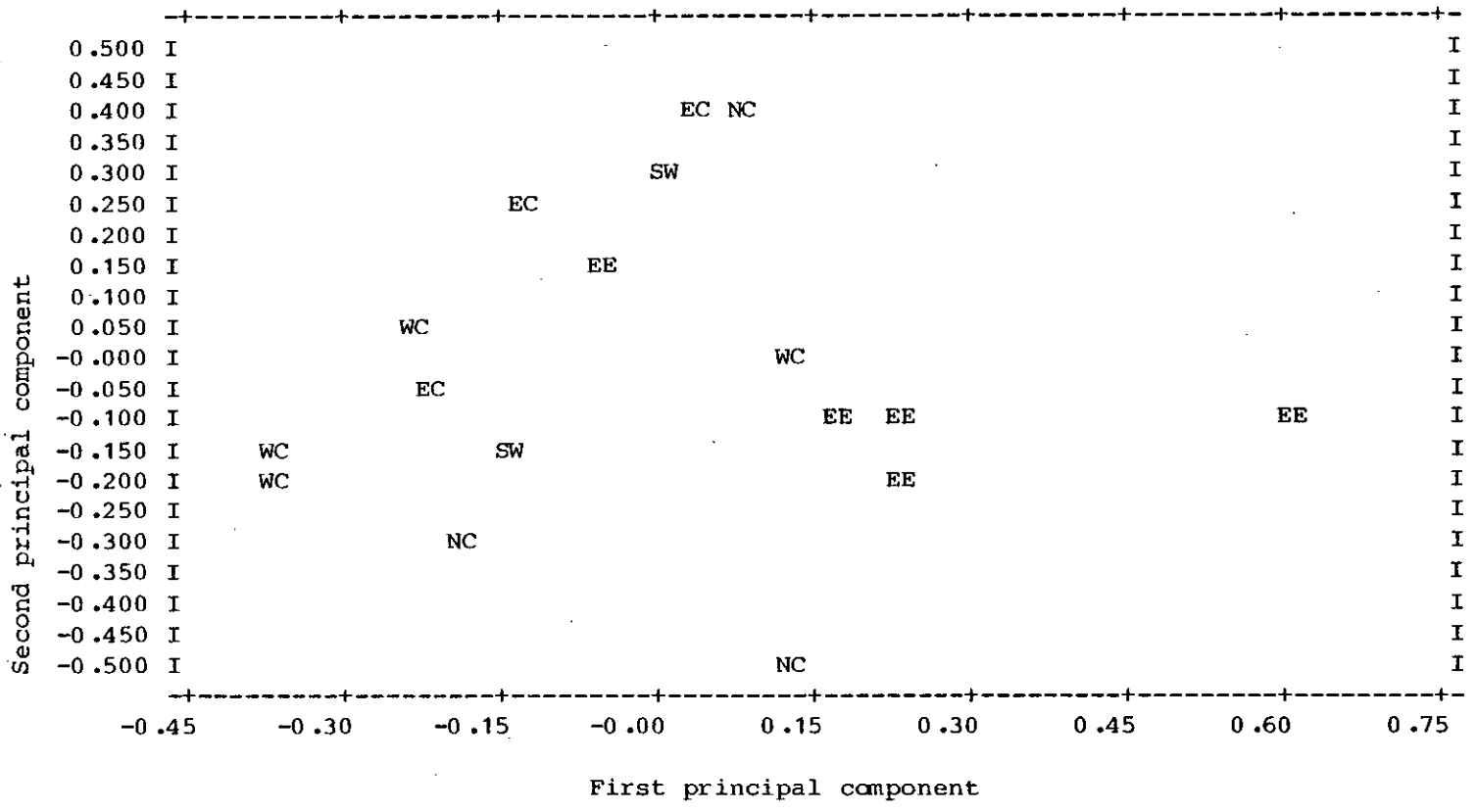
Graph 13

A graph of the residuals from FITCON against the quantiles of the standard Normal distribution.
Variate: total mean yield (adj.), at the English regions during 1969-1978
obtained from NIAB potato trials.



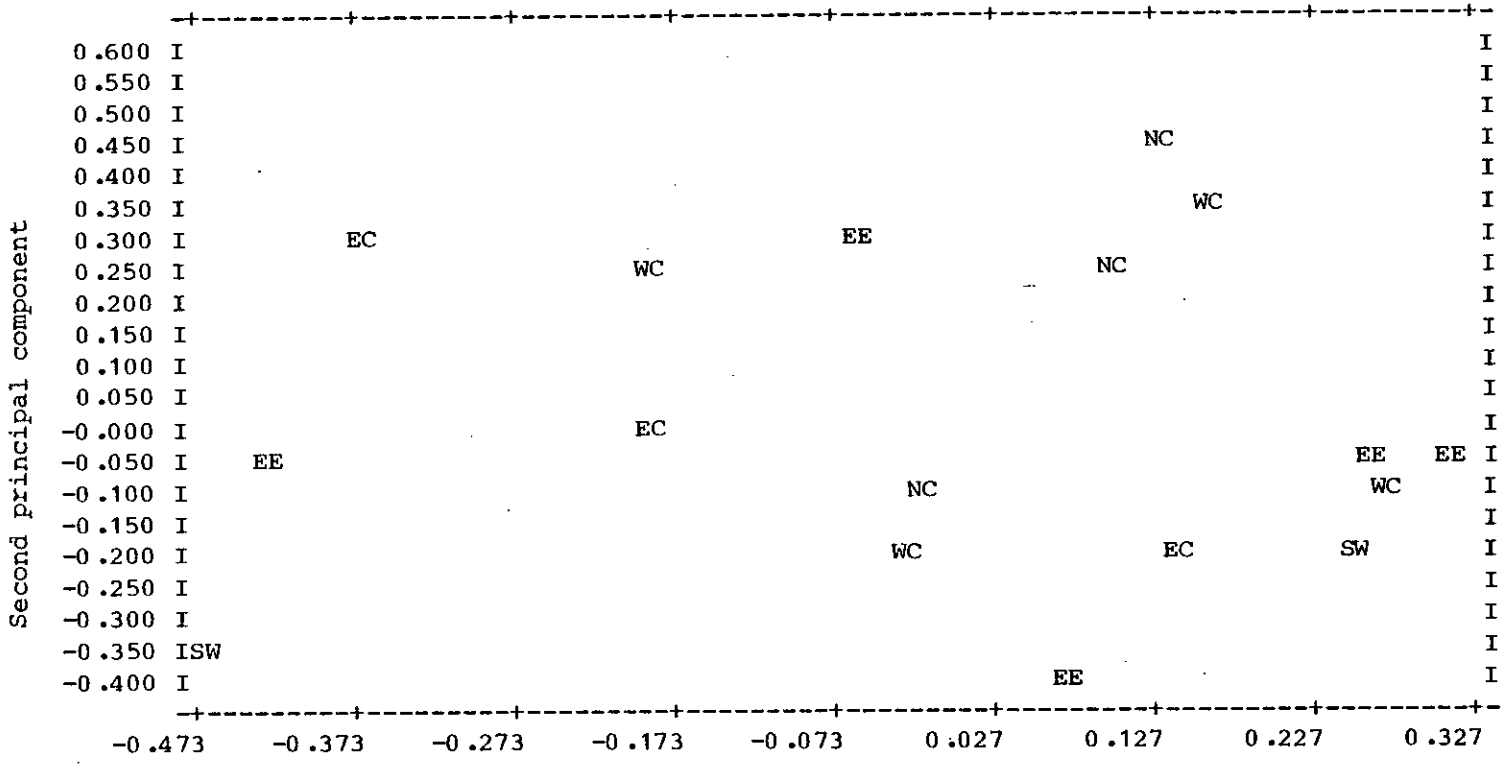
Graph 14

A graph of the first two principal components from analysis of the sites used in the 1969 NIAB potato trials.



Graph 15

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1970.



Graph 16

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1971.

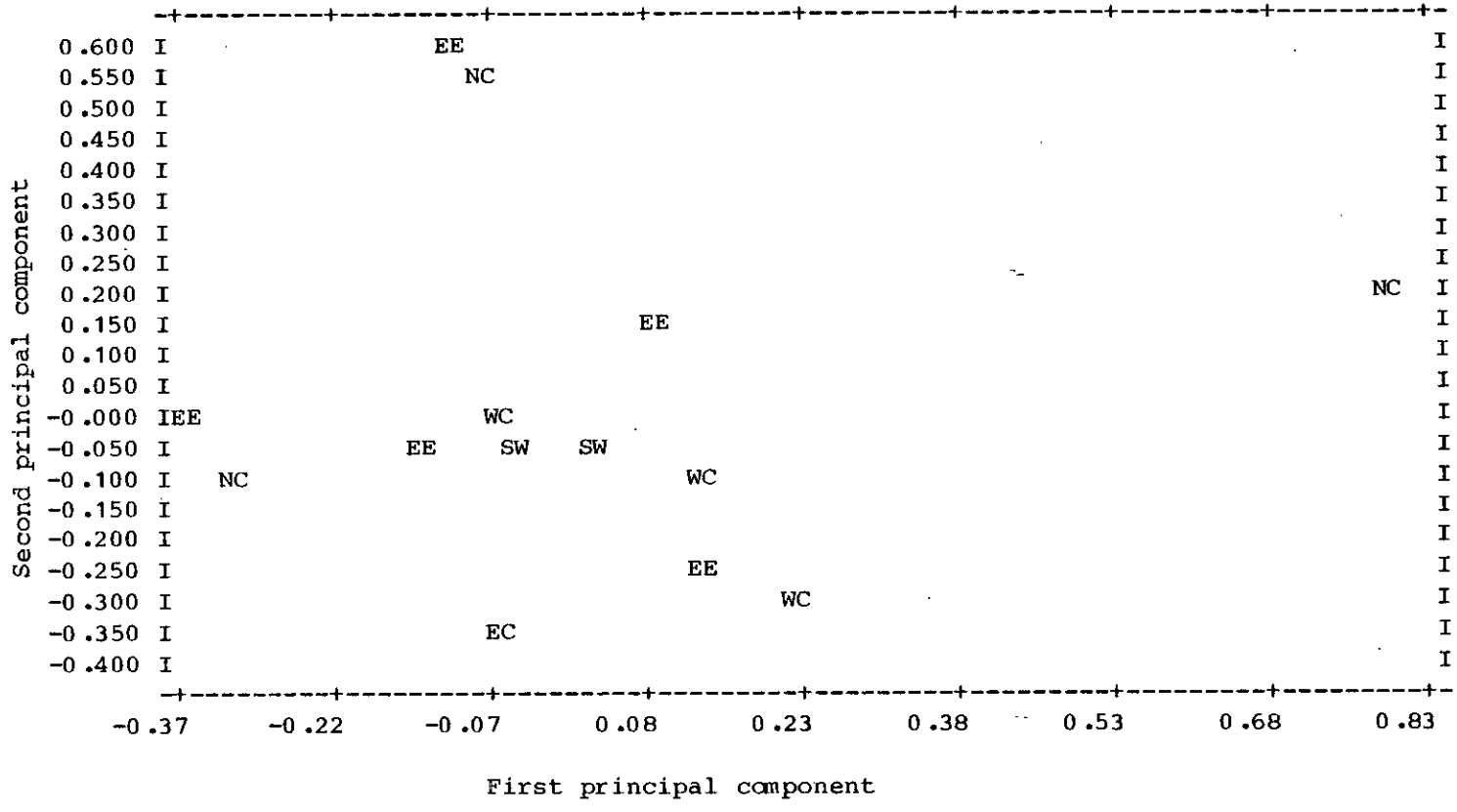
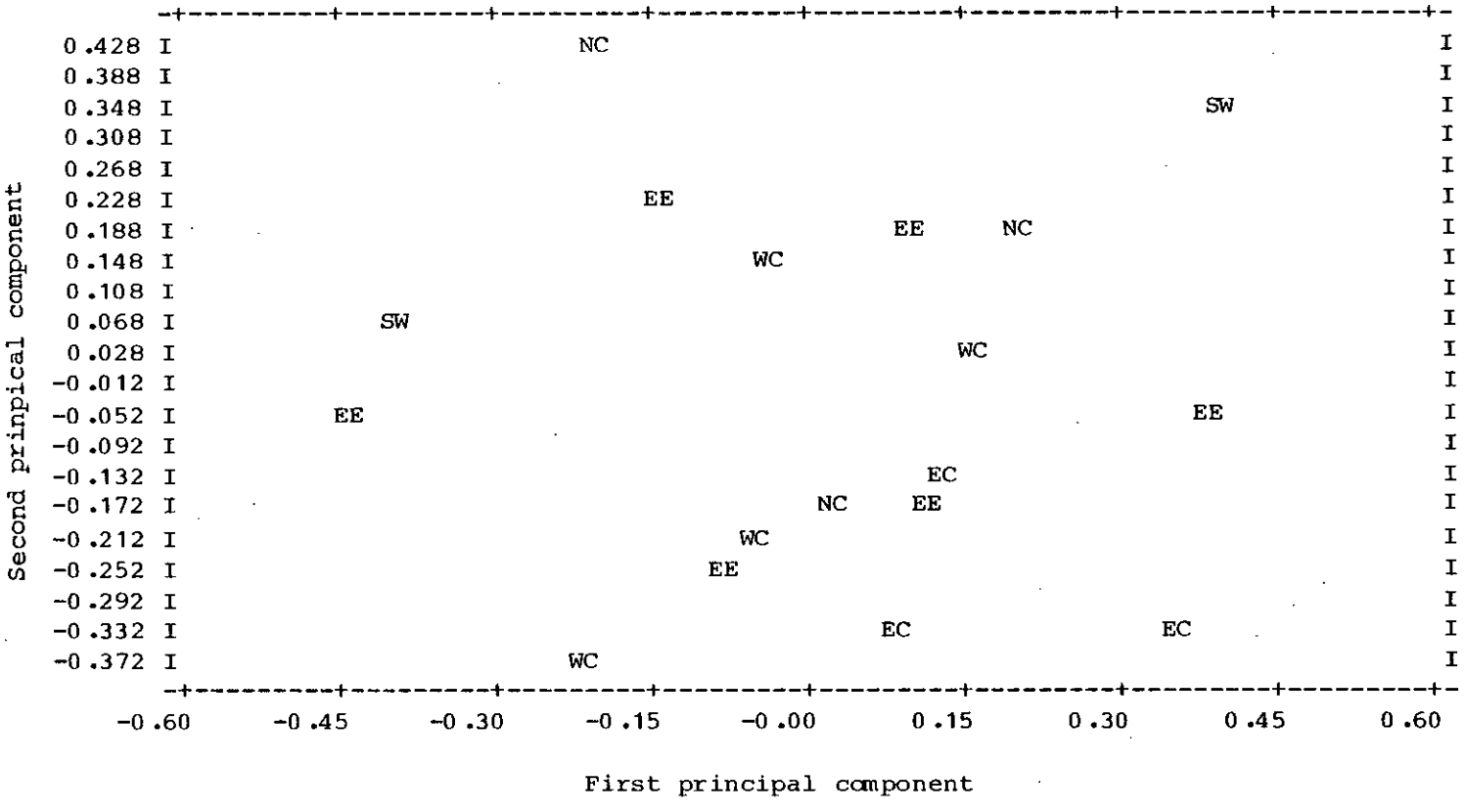


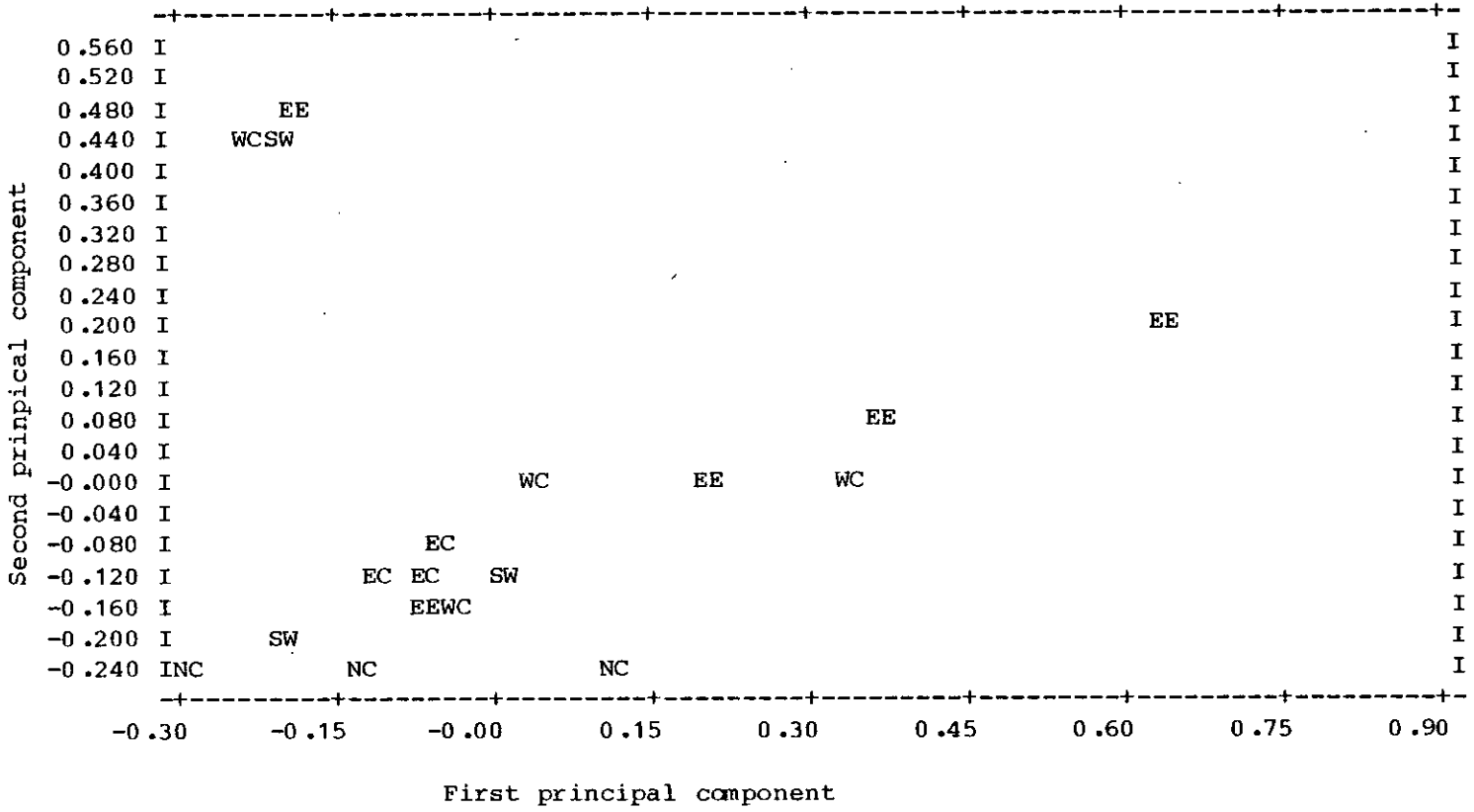
Table 17

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1972



Graph 18

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1973.



Graph 19

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1974

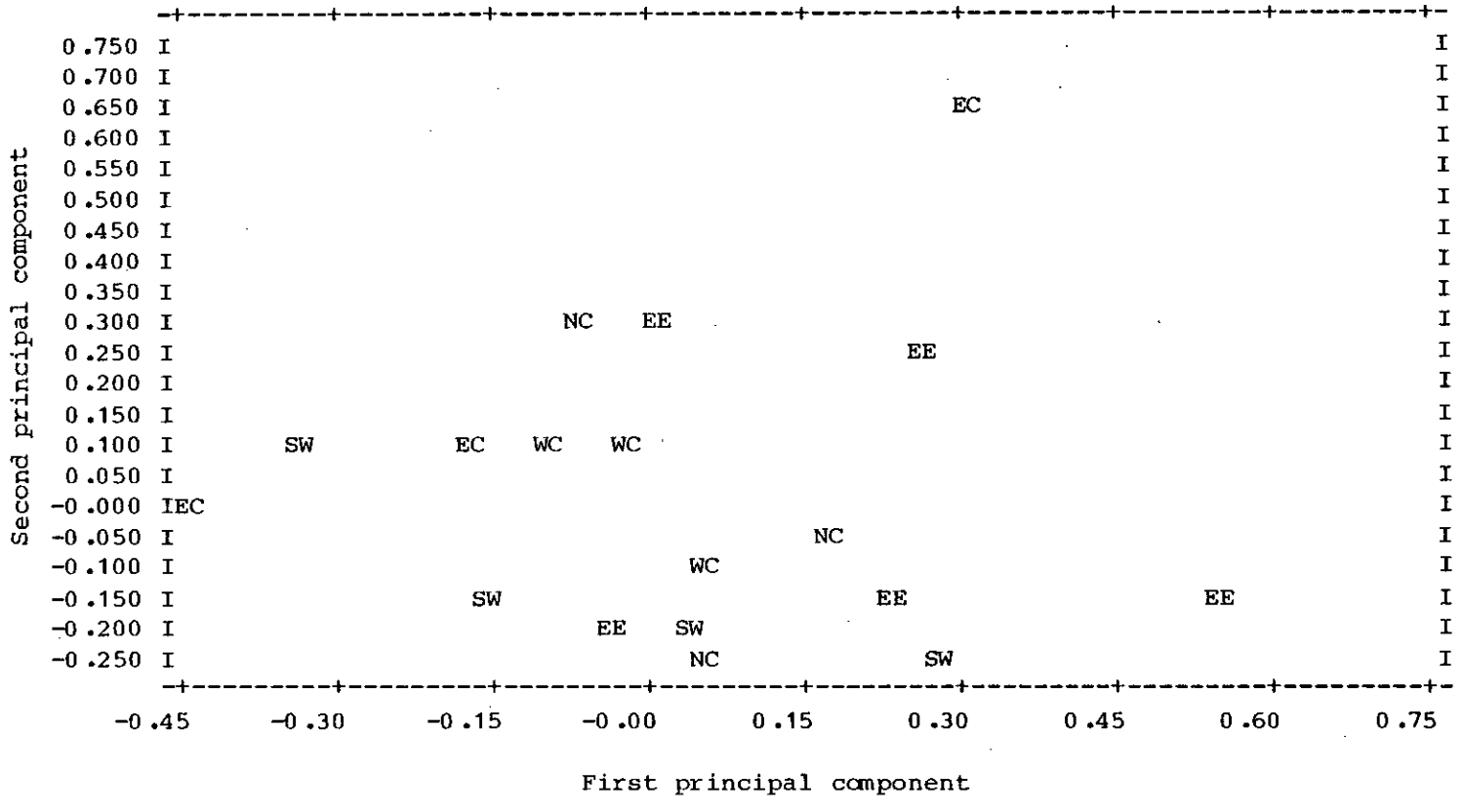
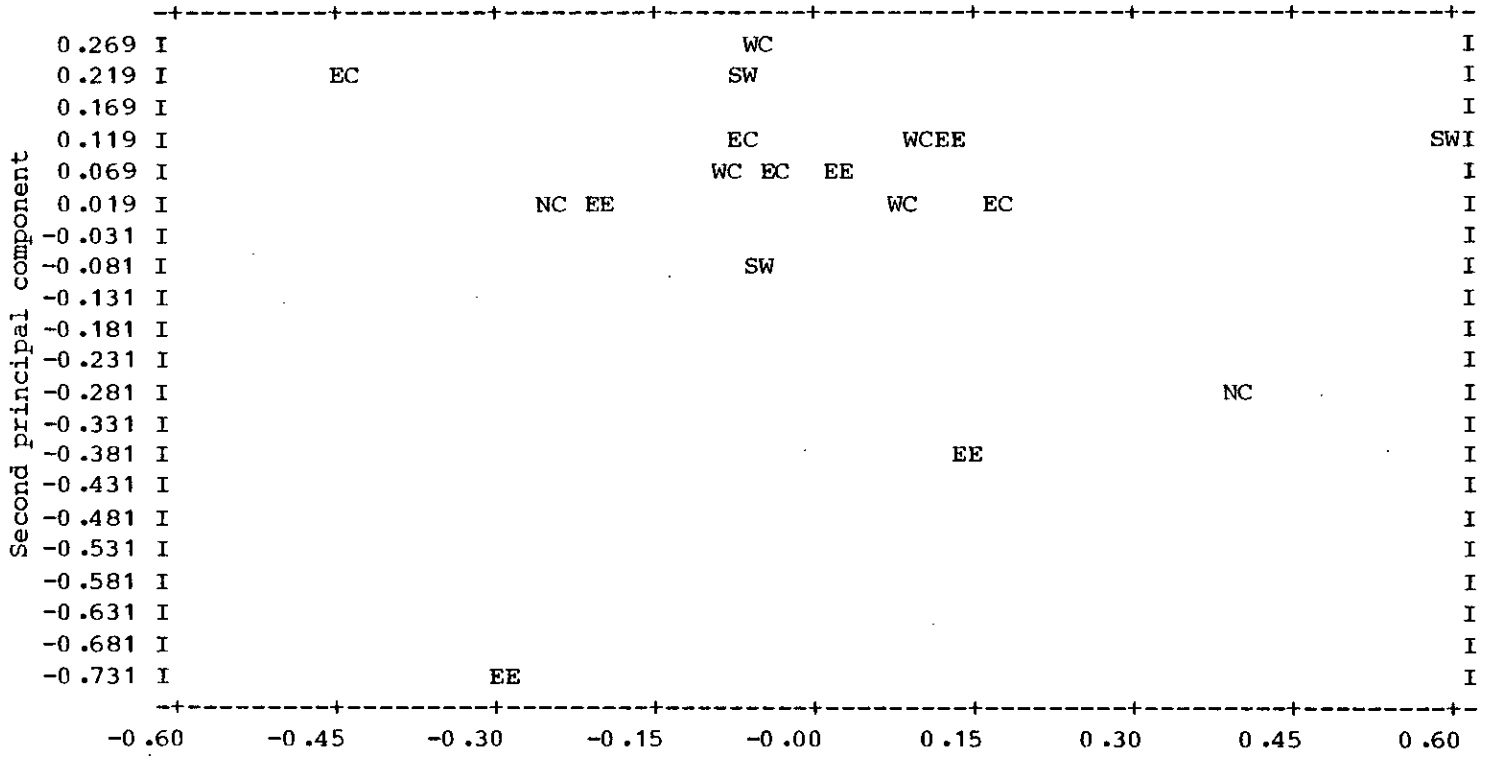


Table 20

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1975



Graph 21

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1976.

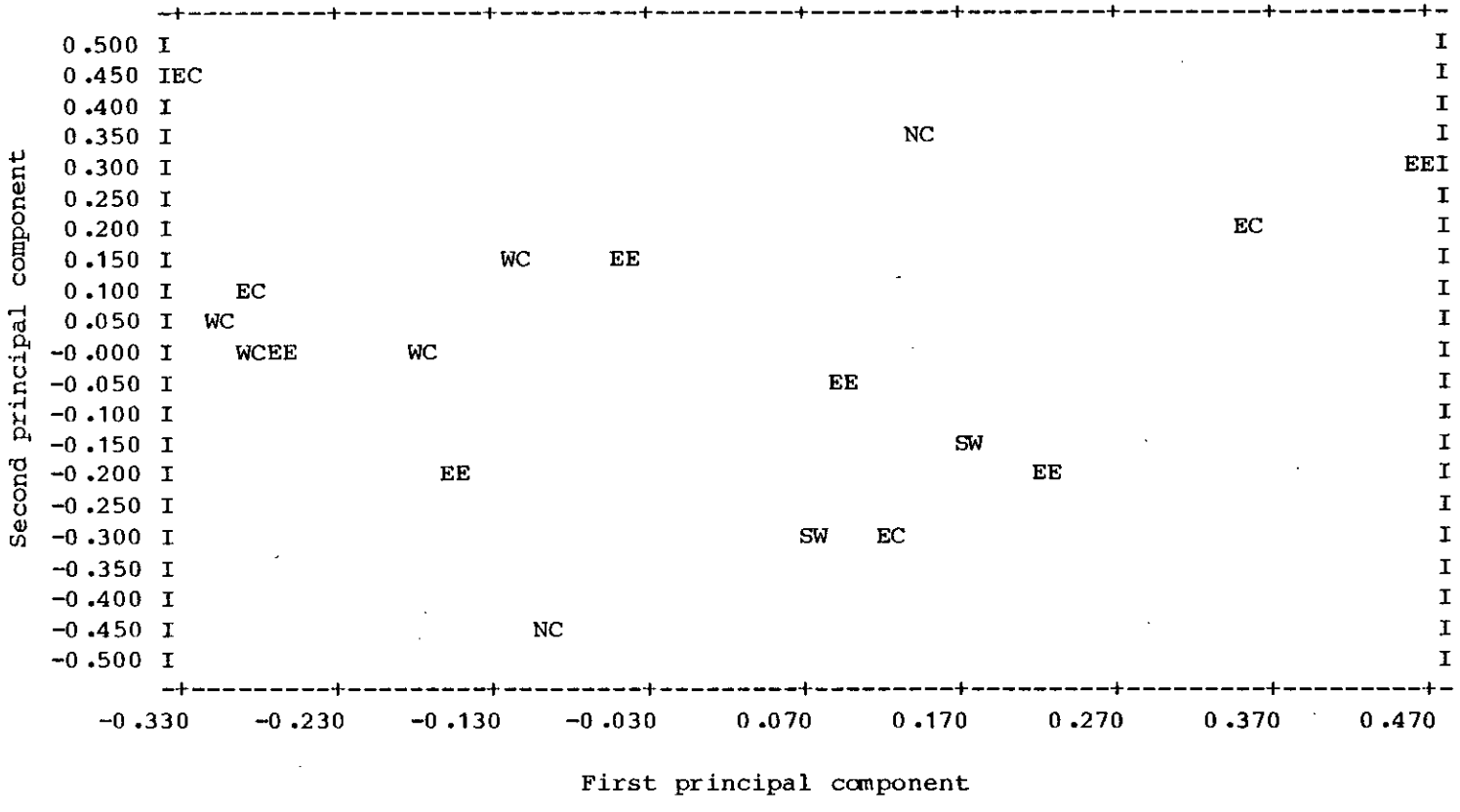
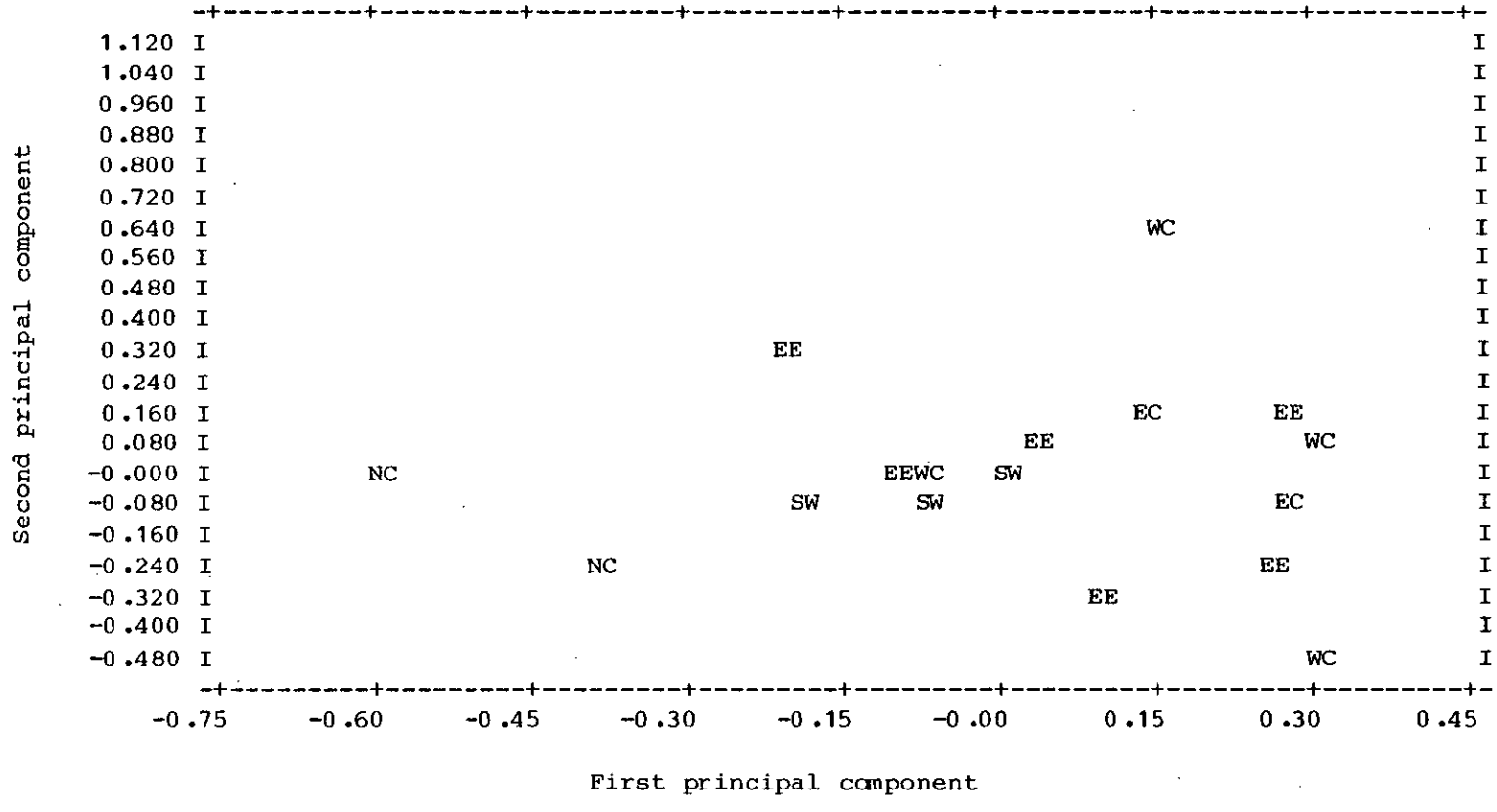


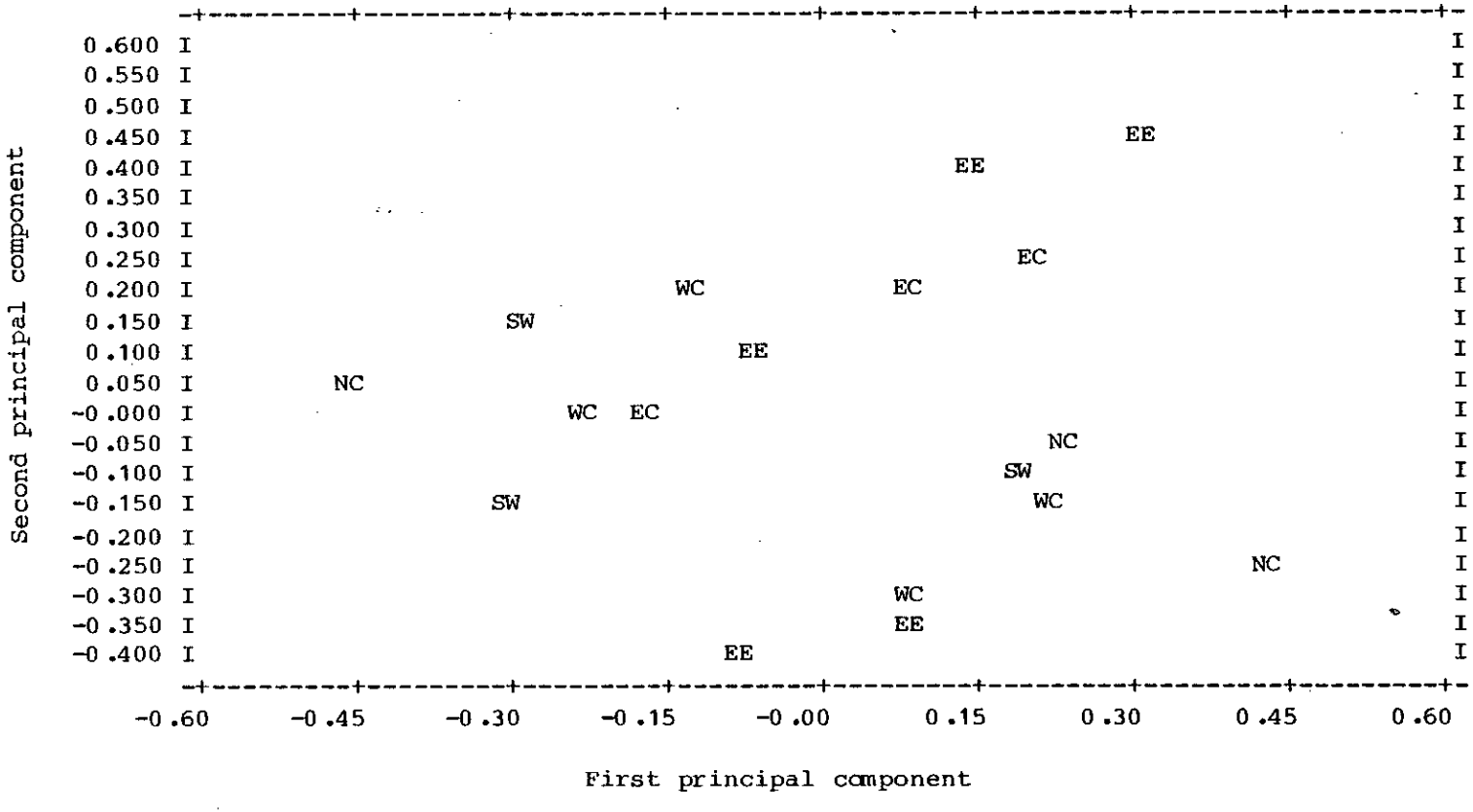
Table 22

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1977



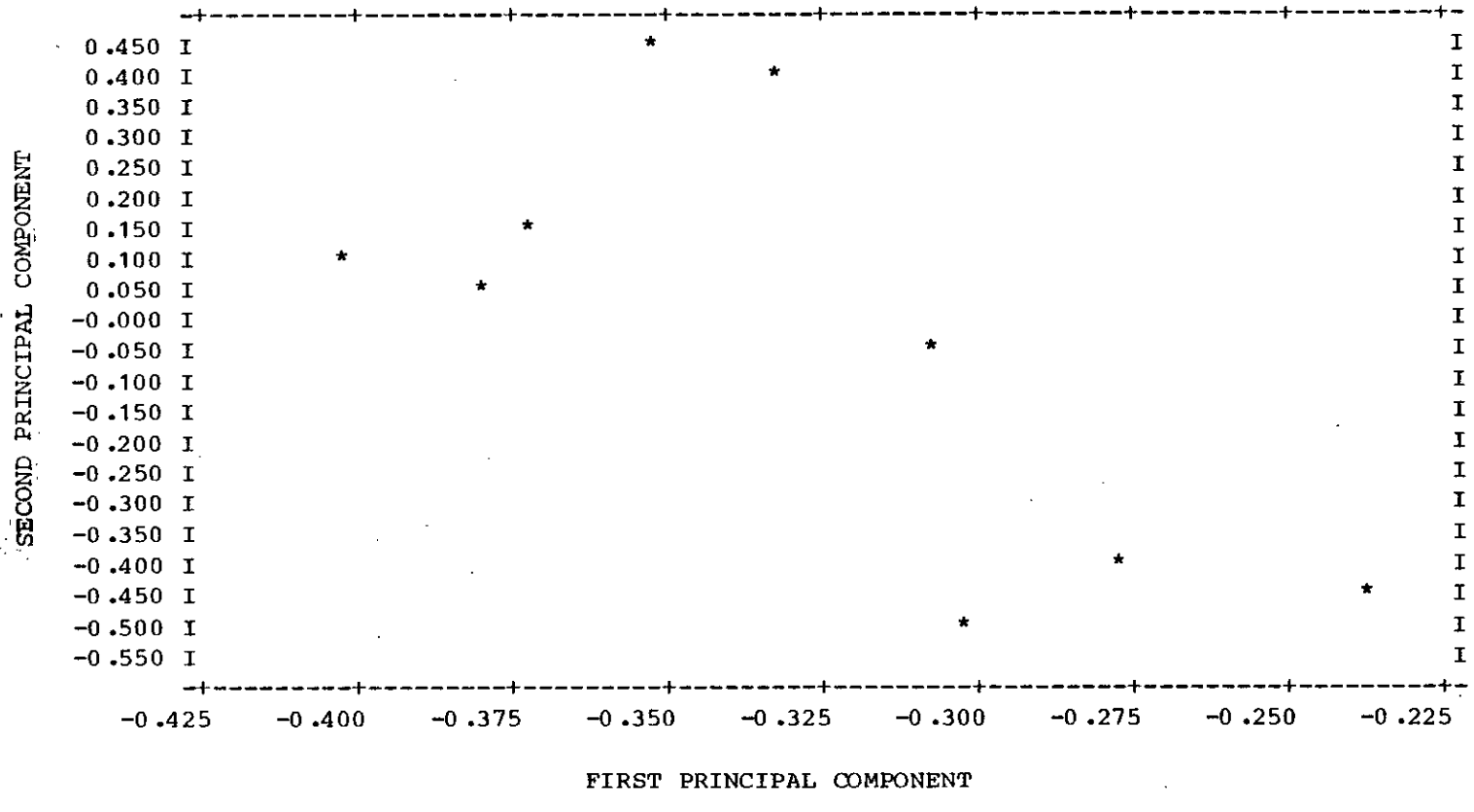
Graph 23

A graph of the first two principal components from the analysis of the sites used in the NIAB potato trials of 1978



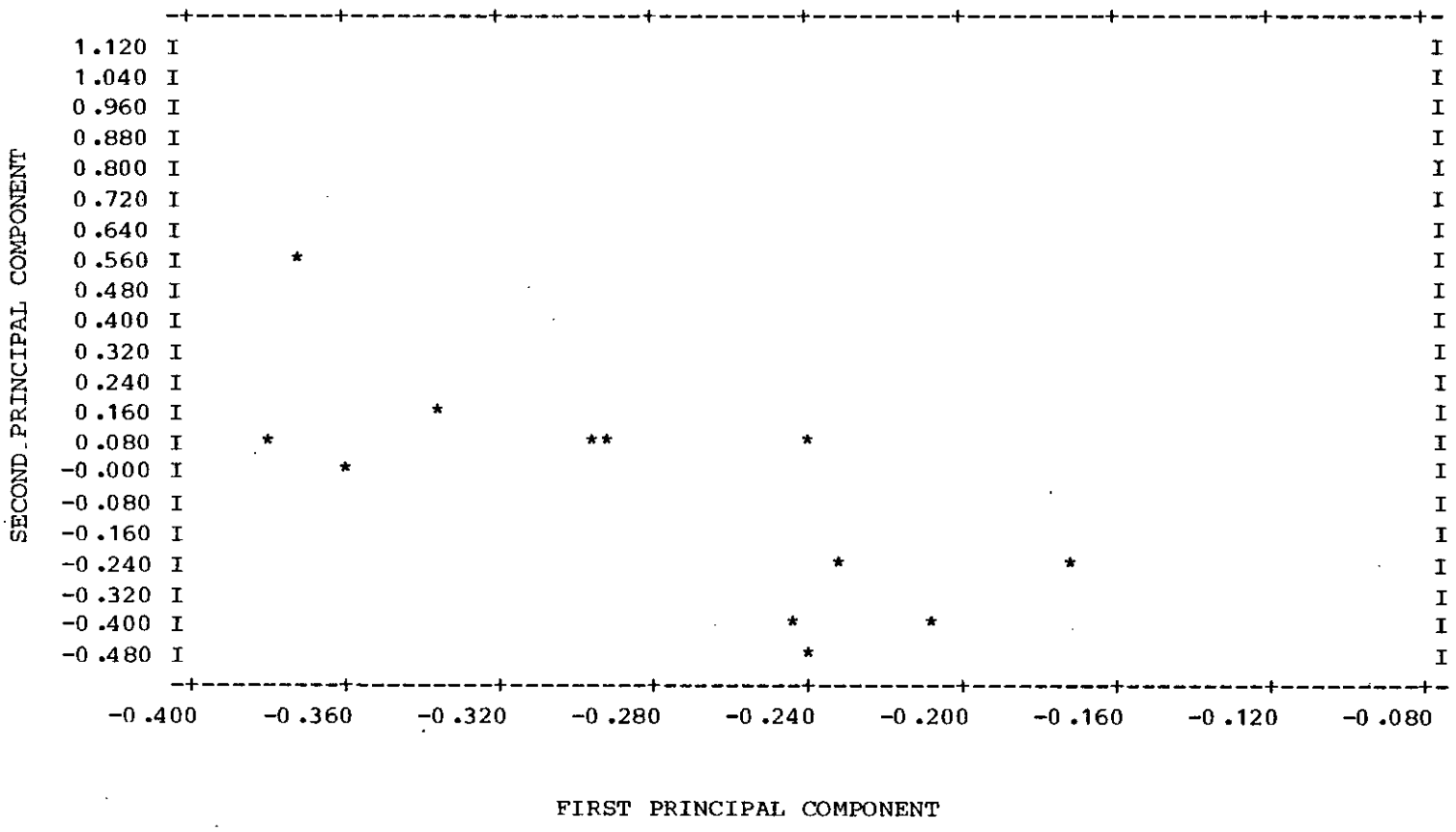
Graph 24

A graph of the first two principal components from the analysis of the varieties in NIAB potato trials in 1969.



Graph 25

A graph of the first two principal components from the analysis of the varieties in NIAB potato trials in 1970.



Graph 26

A graph of the first two principal components from the analysis of the varieties in NIAB potato trials in 1974

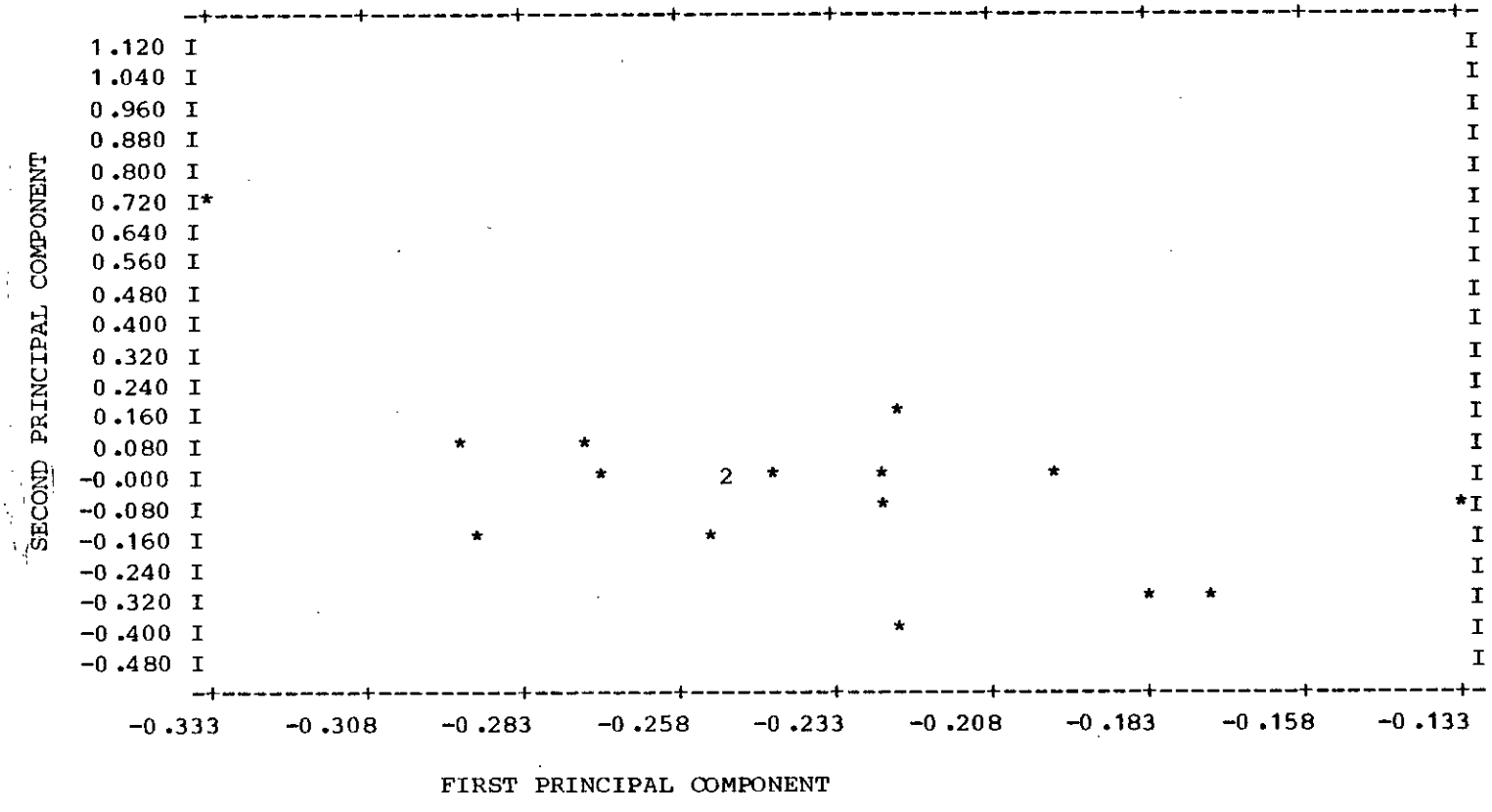
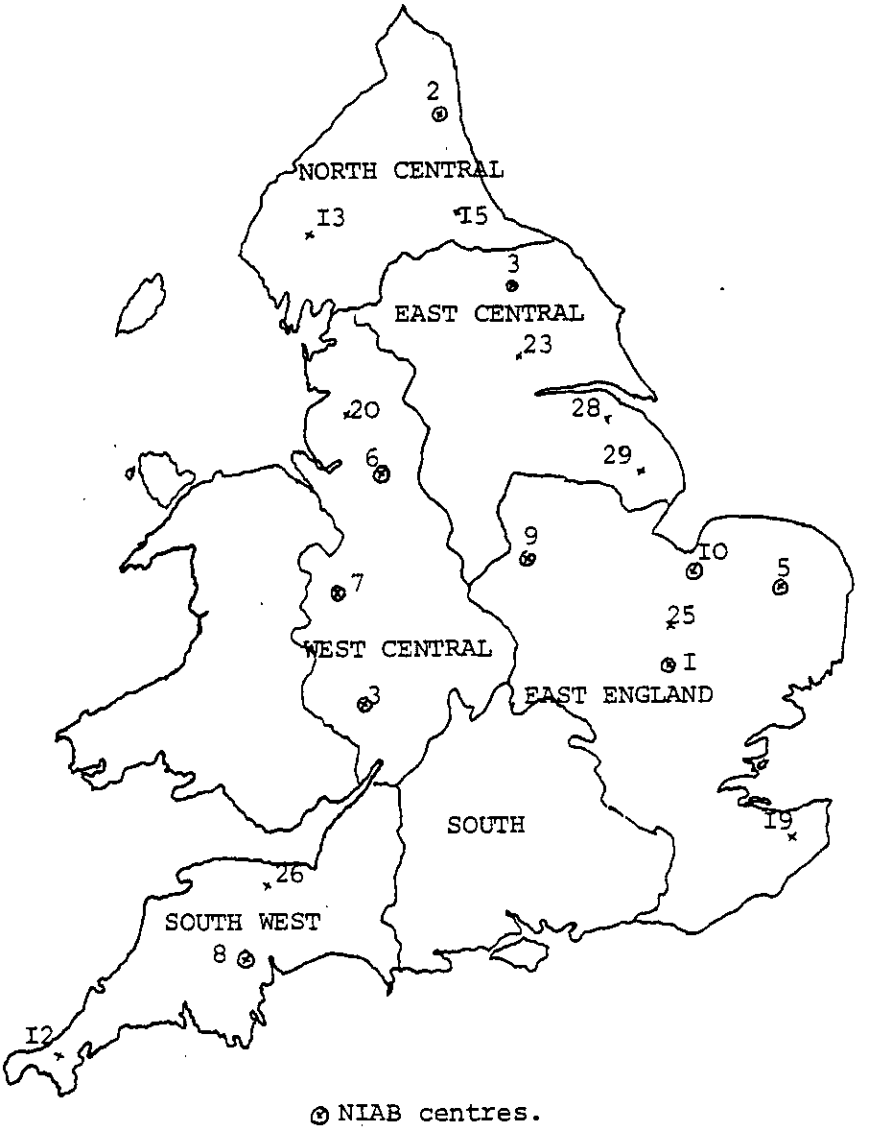


DIAGRAM L

A map of England and Wales showing the approximate location of the centres used in maincrop potato trials, performed by NIAB, in I969-I978.

The regions follow the NIAB definitions.



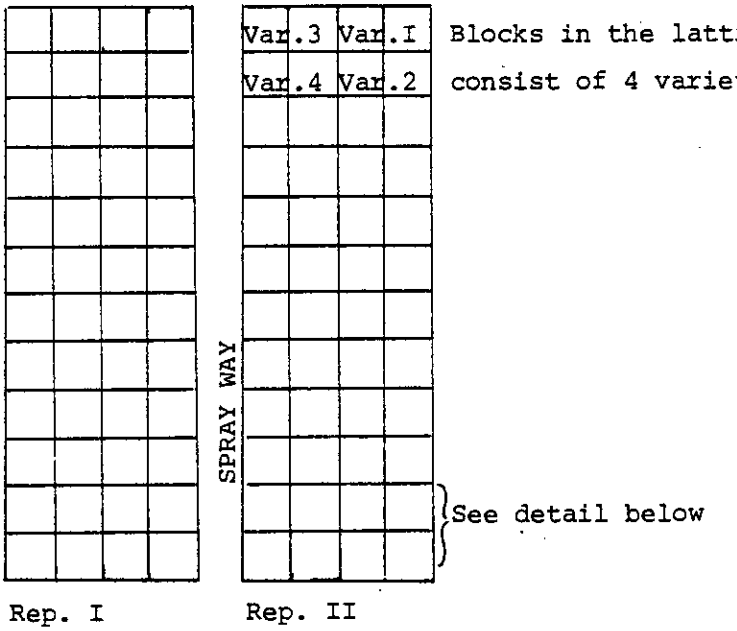
⊗ NIAB centres.

× ADAS centres.

See Table 9 for site codes.

TABLE IA

Field plan of SPBS Regional maincrop trials in I979.



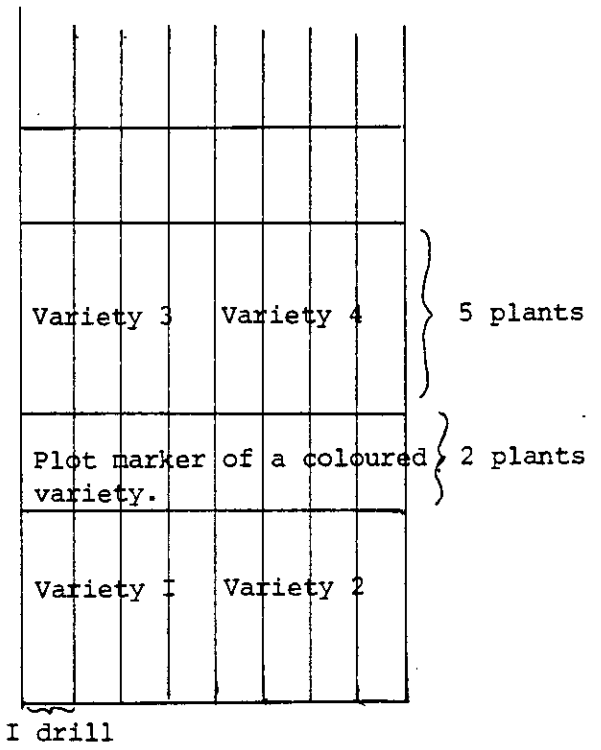


Table 2A

Two analyses of the SPBS Regional Maincrop trial at The Murrays in 1979.
Variate: total yield per plot.

GENERALISED LATTICE ANALYSIS.

Source	df	Sum of Squares	Mean sum of squares
Super-blocks	1	1.6503	1.6503
Blocks(adj)	10	86.1950	8.6195
Variety(unadj)	23	1027.4514	44.6718
Variety(adj)	23	647.9330	28.1710
Residual	13	100.3392	7.7184
Total	47	1215.6362	

SE = 2.03
CV = 8.0%

Notes:
SE, Standard error
CV, Coefficient of variation

RANDOMISED COMPLETE BLOCK ANALYSIS.

Source	df	Sum of squares	Mean sum of squares
Super-blocks	1	1.6502	1.6502
Variety	23	1027.4531	44.6719
Residual	23	186.5348	8.1102
Total	47	1215.6362	

SE = 2.01
CV = 8.2%

Table 3A

Summary of the SPBS/PBI Regional Maincrop Trials (1979), analysed as randomised complete block designs (RCB) and generalised lattice (GL) designs.

Grade: ware

Site	Terrington		Rickwood		The Murrays	
Mean yield Kg/plot	27.6		13.8		33.5	
Analysis	RCB	GL	RCB	GL	RCB	GL
RMS	2.6	3.4	10.2	5.0	8.7	8.1
SE	1.1	1.3	2.3	1.9	2.1	2.1
CV%	5.8	6.7	23.2	16.3	8.8	8.5
RMS_{RCB}/RMS_{GL} %	76		203		107	

Grade: total yield

Site	Terrington		Rickwood		The Murrays	
Mean yield Kg/plot	29.3		15.4		34.9	
Analysis	RCB	GL	RCB	GL	RCB	GL
RMS	2.2	2.3	9.8	5.7	8.1	7.7
SE	1.1	1.1	2.2	2.0	2.0	2.0
CV%	5.2	5.1	20.3	15.6	8.2	5.1
RMS_{RCB}/RMS_{GL} %	104		170		105	

Each trial consisted of 2 super-blocks and each super-block comprised 6 blocks of 4 varieties. The Gleadthorpe trial had one replicate planted incorrectly and could only be analysed as a RCB design.

RMS Residual mean square
SE Standard error
CV Coefficient of variation

Table 4A

Summary of the SPBS/PBI Regional Maincrop Trials (1980), analysed as a randomised complete block design (RCB) and a generalised lattice (GL) design.

Grade: ware

Site	Cambridge		Gleadthorpe		Terrington		Rickwood		The Murrays	
Mean yield Kg/plot	41.1		28.0		34.5		29.7		36.9	
Analysis	RCB	GL	RCB	GL	RCB	GL	RCB	GL	RCB	GL
RMS	5.9	5.7	8.0	5.4	6.8	3.8	7.8	5.6	7.9	5.6
SE	1.4	1.4	2.0	1.8	1.5	1.3	1.6	1.5	1.6	1.5
CV%	5.9	5.8	10.1	8.3	7.6	5.6	9.4	8.0	7.6	6.4
RMS RCB /RMS GL %	105		149		181		140		141	

Grade: total yield

Site	Cambridge		Gleadthorpe		Terrington		Rickwood		The Murrays	
Mean yield Kg/plot	48.4		31.3		39.4		32.2		39.6	
Analysis	RCB	GL	RCB	GL	RCB	GL	RCB	GL	RCB	GL
RMS	5.1	5.2	7.0	3.2	7.2	4.0	10.3	5.3	7.4	4.6
SE	1.3	1.3	1.9	1.5	1.6	1.3	1.8	1.5	1.6	1.4
CV%	4.7	4.7	8.5	5.8	6.8	5.1	10.0	7.2	6.9	5.4
RMS RCB /RMS GL %	100		212		180		194		163	

RMS Residual mean square
SE Standard error
CV Coefficient of variation

Table 5A

A summary of the generalised lattice (GL) and randomised complete block (RCB) analyses of the 'NIAB demonstration' trial at The Murrays in 1979.

Grade :	Ware		Total yield	
Mean yield Kg/plot:	7.76		8.56	
Analysis:	RCB	GL	RCB	GL
RMS	0.588	0.444	0.474	0.294
SE	0.384	0.354	0.344	0.291
CV%	9.9	8.6	8.0	6.3
RMS /RMS % RCB GL	132		161	

RMS Residual mean square
SE Standard error
CV Coefficient of variation

Table S1
A split-plot analysis of The Murrays 1978 spacing experiment. Variate: total yield per plot, only the centre rows of each plot were harvested.

GENSTAT computer output.

Source	df	Sums of Squares	Mean Square	F
Blocks	2	20.997	10.498	5.94*
Spacings	2	240.677	120.338	10.79*
Residual	4	44.611	11.153	
Total	6	285.288		
Varieties	9	417.253	46.361	17.30*
Varieties x spacings	18	45.331	2.518	0.94
Residual	51(3)	136.700	2.680	
Blocks.Plots.Subplots.Reps	87(3)	153.752	1.767	
Total	173	1059.320		

Grand estimated plot mean 8.30kg/plot

Table S2
A split-plot analysis of The Murrays 1978 spacing experiment. Variate: total yield per plot, all rows of each plot were harvested.

GENSTAT computer output.

Source	df	Sums of Squares	Mean Square	F
Blocks	2	23.921	11.96	7.34*
Spacings	2	513.837	256.918	15.86*
Residual	4	64.800	16.200	
Total	6	578.657		
Varieties	9	785.225	87.247	31.64*
Varieties x spacings	18	46.850	2.603	0.94
Residual	51(3)	140.622	2.757	
Blocks.Plots.Subplots.Reps	261(9)	425.019	1.628	
Total	347	2000.274		

Note: Ulster Sceptre did not appear in one block due to a lack of seed.
* indicates significance at the 5% level.

Table 1E

Weight of tubers recovered when the 1978 split-plot experimental site was re-dug to gather the remaining tubers after harvest.

All weights are measured in Kgs.

	Harvest weight	Repick weight	Repick/harvest%
Total weight	2923.96	61.73	2.11
Oversized grade 80mm	644.48	1.90	0.29
Correct sized grade 40mm-80mm	2125.72	50.47	2.37
Undersized grade 40mm	153.76	9.36	6.09

Table 1G

Randomised complete block analysis of the 1979 experiment at The Murrays.
Variate: total yield
Produce from the centre rows of each plot harvested.

GENSTAT computer output

Source	df	Sum of squares	Mean sum of squares	F
Blocks	3	12.158	4.053	3.9*
Varieties	7	37.442	5.346	5.5*
Residual	21	20.247	0.964	
Blocks.varieties.plots	32	33.160	1.036	
Total	63	103.007		

Table 2G

Randomised complete block analysis of the 1979 experiment at The Murrays.
Variate: total yield
Produce from the entire plot harvested.

GENSTAT computer output

Source	df	Sum of squares	Mean sum of squares	F
Blocks	3	27.358	9.119	8.8*
Varieties	7	83.592	11.942	9.0*
Residual	21	27.835	1.326	
Blocks.varieties.plots	96	99.192	1.033	
Total	127	237.995		

Notes: * indicates significance at the 5% level.

Table R1

Precentage of yield which is 'saleable' (sound tubers between 35mm-80mm) harvested from the centre rows of the 1979 experiment at The Murrays.

Spacing: 12ins within the row

Variety	Percentage of total yield saleable
Edzell Blue	91
Majestic	85
Pentland Raven	96
Pentland Squire	87
Stormont Enterprise	84
Record	97
Croft	89
Désirée	98

Table R2

Percentage of total yield which is 'saleable' (40mm-80mm), harvested from the centre rows of each plot of the 1978 experiment at The Murrays.

Variety	Spacing 9''	15''	21''
Bintje	93	78	73
Croft	81	75	69
Désirée	66	62	60
Maris Peer	73	73	70
Maris Piper	67	75	74
Pentland Crown	88	80	84
Pentland Hawk	63	60	56
Pentland Javelin*	51	54	57
Pentland Squire	77	77	67
Ulster Sceptre*	59	69	61

* indicates that the variety is an 'early' rather than a 'maincrop' variety.

REFERENCES.

Allen, E.J., Effects of planting and growth of contrasting potato varieties. in Pembrokshire. J.Agric.Sci.(1977) 89 711-735

Allen,E.J., Scott, R.K., An analysis of growth of the potato crop. J.Agric.Sci.(1980) 94 583-606

Ary, A.C., Further experiments in field technic in plot tests. J.Agric.Sci. (1921) 21 483-499

Ary, A.C., Hayes, H.K., Experiments in field technic in plot tests. J.Agric.Res. (1918) 15 251-262

Bleasdale, J.K. Relationship between set characters and yield in maincrop potatoes. Agric.Sci.(1965) 64 361-366

Boyd, D.A., Lessels, W.J., The effect of seed rate on the yield of potatoes. J.Agric.Sci.(1954) 44 465-76

Brown, B.A., Plot Competition with potatoes. J.Am.Soc.Agron. (1922) 14 257-258

Bradu, D., Gabriel, K.R., The Biplot as a diagnostic tool for models of two-way tables. Technometrics (1978) 20 47-68

Burstall, L., (1980) Personal Communication.

Cattell, R,B., The Scree test for the number of factors. Multivariate Behav. Res. (1966) 1 245-276

Chittenden, F.J., The effect of 'place' on yields of crops. J.Roy.Hort.Soc. (1919) 44 72-74

Cochran, W.G., Cox, G.M., Experimental Designs. Wiley, New York. 2nd Ed. (1957)

Comstock, R.E., Moll, R.H., Genotype environment interactions. In Ststistical Genetics and Plant Breeding. (1963) NAS-NRC no. 982, 164-96

Currance,F.A., Krantz,T.N., The relation of plot size and shape to potato yield. Am.Pot.Jour. (1936) 310-131

Day, J.W., The relation of size, shape and number of replications of plants to probable error in field experimentation. J.Am.Soc.Agron. (1920) 12 100

Digby, P.G., Modified joint regression analysis for incomplete varietyxenvironment data. J.Agric.Sci. (1979) 93 81-86

Draper, N.R., John, J.A. Testing for three or fewer outliers in two-way tables. Technometrics (1980) 22 9-15

Eberhart, S.A., Russell, W.A., Stability of adaption in a plant breeding programme. Crop Sci. (1966) 6 36-40

Evans, S.A., Maximum potato yield in the United Kingdom. Outlook on Agriculture (1975) 8 184-7

Federer, W.T., Robson, D.S., General theory of prime power lattice designs. Incomplete block design and analysis for p varieties in p plots. Cornell University Agricultural Experimental Station Memoir 509 1-37

Finlay, K.W., Wilkinson, G.N., The analysis of adaptation in a plant breeding programme. Australian J.Agric.Res. (1963) 14 742-54

Finney, D.J., An introduction to the theory of experimental design, University of Chicago Press (1960)

Fisher, R.A., The Design of Experiments. 8th Ed. Oliver and Boyd, Edinburgh (1966)

Fisher, R.A., Machenzie, W.A., Studies in Crop Variation. II The manurial response of different potato varieties. J.Agric.Sci.(1923) 13 311-320

Freeman, G.H., Analysis of interactions in incomplete two-way tables. Applied Statistics (1975) 24 46-55

French, W.M., (1981) Personal Communication.

Gentleman, J.F., Wilk, M.B., Detecting outliers II. Supplementing the direct analysis of residuals. Biometrics (1975) 31 387-410

Good, I.J., Some applications of the Singular Value Decomposition of a matrix. Technometrics (1969) 11 823-831

Haliburn, C., Resolvable row and column designs. MSc Thesis, (1980) Edinburgh University.

Hanley, F., Jarvis, R.H., Ridgman, W.J., The effects of fertilizers on the bulking of Majestic potatoes. J.Agric.Sci. (1965) 65 159-169

Harris, J.A., Practical universality of yield heterogenity as a factor in influencing plot yields. J.Agric.Res. (1920a) 19 279-314

Harris, J.A., Permanence of differences in plots of an experimental field. J.Agric.Res. (1920b) 20 335-356

Harris, J.A., Scofield, C.S., Further studies on the permanance of differences in the plots of an experimental field. J.Agric.Res. (1928) 36 15-41

Harris, P.M., The Potato Crop, (ed) Chapman and Hall, London (1978)

Harshbarger, B., Triple rectangular lattices. Biometrics (1949) 5 1-13

Holden, J.H., Potato Breeding at Pentlandfield SPBS Annual Report 1976-77 (Extract)

Hornsey, K.G., Screening for yield in sugar beet. Abstract from AAB(PBG) and FBPP Meeting, Edinburgh (1979)

Ifenkwe, O.P., Allen, E.J., Effect of row width and planting density yield of two maincrop potato varieties. 2. Number of tubers, total and graded yields and their relationships with above-ground stem densities. J.Agric.Sci.(1978) 91 279-289

Jacobs, W.C., Some general considerations of plot technique in horticulture. Proc.Am.Soc.Hort.Sci. (1953) 62 35-45

Jarvis, R.H., An assessment of the value of different sizes of seed potatoes of maincrop varieties. Experimental Husbandry (1977) 32 102-114

Jarvis, R.H., Population studies with Pentland Crown and Pentland Dell potatoes. Expl.Husb. (1971) 20 84-92

Jarvis, R.H., Shotten, F.E., Comparison of 30ins and 36ins rows for maincrop potatoes. Part I Effect on yield. Expl.Husb. 21 78-84

John, J.A., Prescott, P., Critical values of a test to detect outliers in factorial experiments. Applied Stats. (1975) 24 56-59

Justesen, S.H., Influence of size ans shape of plots on the precision of field experiments with potatoes. J.Agric.Sci. (1932) 22 366-372

Kalamkar, R.J., Experimental error and field plot technique with potatoes. J.Agric.Sci. (1932) 22 373-383

Kaltsikes, P.J., Genotype-environment interaction variances in yield trials of Fall rye. Canadian J.Plant Sci. (1970) 20 77-80

Kawakami, K., Physiological aspects of potato seed tubers. Mem.Hyogo.Agric.College (1952) 1-114

Kemthorne, O., Design and Analysis of Experiments. Wiley (1952)

Killick, R.J., (1980) Personal Communication.

Killick, R.J., (1981) Personal Communication.

Kirienko, A.I., Effect of tuber size and nutrition area on potato yield. Field Crop Abstracts (1979) 32 668

Kisselback, T.A., Competition as a source of error in corn yield. J.Am.Soc.Agric. (1923) 15 199

Lambert, J.W., Rassussen, D.C., Variety environment interactions in barley tests. Crop Sci. (1961) 1 261-2

Lana, E.P., Homeyer, P.G., Haber, E.E., Field plot technique in vegetable crops. Proc.Am.Soc.Hort.Sci. (1953) 62 174-179

Large, E.C., The battle against blight. Agriculture, London (1959) 603-8

Madec, P., Perennec, P., Les Possibilities d'evolution des germes de la pomme de terre et leurs consequences. Annales de l'amelioration des Plantes (1955) 5 555-574

Mardia, K.V., Kent, J.T., Bibby, J.M., Multivariate Analysis. Academic Press Inc. (1979)

McDermott, N., Ivinns, J.D., Rainfall as a factor influencing the yield of potato crops. NAASQ Rev. (1955) 27 106-108

Munro, I.A., Scourey, L.R., Effect of date on planting on yield of Pentland Crown and King Edward potatoes. Experimental Husbandry (1976) 31 120-124

Musgrave, G.W., Depression of check row yields by adjoining high yielding plot rows in potatoes. J.Am.Soc.Agron. (1924) 16 633

Myers, C.H., Perry, F.R., Analysis and interpretation of data obtained in comparative tests of potatoes. J.Am.Soc.Agron. (1923) 15 239-253

NIAB Classified list of potato varieties in England and Wales, 1977/78

NIAB Recommended varieties of potatoes 1977/8 Farmers' Leaflet No.3

Nonneck, I.L., Smillie, K.W., Precision of field experiments with vegetable crops as influenced by plot size and shape. III Potatoes. Can.J.Plant Sci. (1964) 44 57

Palmer,G.M.. Jarvis, R.H., Effect of type of planter on the yield of maincrop potatoes from sprouted and unsprouted seed planted at different dates. Experimental Husbandry (1976) 31 52-63

Patterson, H.D., Routine least squares estimation of variety means in incomplete tables. J.natn.Inst.agric.Bot. (1978) 14 401-412

Patterson, H.D., Thompson, R., Recovery of inter-block information when block sizes are unequal. Biometrika (1971) 58 545-54

Patterson, H.D., Thompson, R., Maximum likelihood estimation of components of variance. Proc.of the 8th Int.Biometric Con.(1975) 197

Patterson, H.D., Williams, E.R., A new class of resolvable incomplete block designs. Biometrika (1976) 63 83-92

Patterson, H.D., Silvey, V., Talbot, M., Weatherup, S.T.,Variability of yields of cereal varieties in UK trials. J.Agric.Sci. (1977) 89 236-245

Patterson, H.D., Silvey, V., Statutary and Recommended List Trials of crop varieties in the UK. J.Roy.Stat.Soc.A (1980) 143 219-252

Patterson, H.D.,Williams, E.R., Hunter, E.A., Block designs for variety trials. J.Agric.Sci. (1978) 90 395-400

Plaisted, R.L., Peterson. L.C., A technique for evaluating the ability of selections to yield consistently in different locations or seasons. Am.Pot.Jour. (1959) 36 381-385

Popova, R.F., Effect of Tuber size and plant density on total yields and yield of seed tubers of potatoes. Field Crop Abstracts (1980) 33 960

Richardson, D.E., Potato testing at NIAB. J.natn.Inst.agric.Bot. (1979) 15 92-98

Rodrigo, M.A., Alvarado, L.F., Effect of plant populations and earthing up on potato prouction in Narino, Colombia. Field Crop Abstracts (1980) 33 961

Schotten, F.E., Jarvis, R.H., Fertilizer placement trials with maincrop potatoes. Expl.Husb. (1967) 15 24-31

Sekioka, T.T., Lauer, F.I., Some estimates of genotype x environment interaction in potato variety tests. Am.Pot.Jour. (1970) 47 304-309

Shukla, G.K., Application of some multivariate techniques in the analysis and of interpretation the genotype-environment interaction. (1972) Unpublished.

Simmonds, N.W., Comparisons of the yields of four potato varieties in trials and in agriculture. Expt.Agric. (1980) 16 393-398

Simmonds, N.W., (1981) Personal Communication.

Sprent, P., Models in regression and related topics. Methuen, London (1969)

Steward, F.C., Experiments with potatoes. Part II. Row competition and border effect. N.Y.State Exp.Sta.Bull. (1927) 518

Skinner, J.C., Hogarth, D.M., Efficiency of border rows in replicated sugar cane variety trials. Euphytica (1980) 27 629-643

Thompson, R.C., Size, shape, and orientation of plots and number of replications required in sweet potato field-plot experiments. J.Agric.Res. (1934) 48 379-399

Toosey, R.D., The pre-sprouting of seed potatoes: Factors affecting sprout growth and subsequent yield. Parts I II Field Crop Abstracts (1964) 17

Trudgill , D.L., Evans, K., Parrott, D.M., Effects of potato cyst-nematodes on potato plants II. Nematologica (1975) 21 183-91

Van der Paauw, F., Relations between the potash requirements of crops and meteorological conditions. Plant Soil (1958) 9 254-68

Watson, D.J., The growth of the Potato. ed.Ivins, J.D. Milthorpe, F.L., (1963) Butterworths, London

Williams, E.J., The interpretation of interactions in factorial experiments. Biometrika (1952) 39 65-81

Williams, E.R., Patterson, H.D., John, J.A., Resolvable designs with two replications. J.Roy.Stat.Soc.B (1976) 38 296-301

Wilson, J., Chittenden, F.J., Some further experiments with potatoes. J.Roy.Hort.Soc. (1919) 44 83

Wurr, D.C., Some effects of seed size and spacing on the yield and grading of two maincrop potato varieties. Phd. Thesis, University of Cambridge (1971)

Wurr, D.C., Some effects of seed size and spacing on the yield and grading of two maincrop potato varieties.I Final yield and its relationship to plant population. J.Agric.Sci. (1974) 82 37-45

Wurr, D.C., The effect of variation in the storage temperature of seed potatoes on sprout growth and subsequent yield. J.Agric.Sci. (1979) 93 619-622

Wurr, D.C., Morris, G.E., Relationship between the number of stems produced by a potato seed tuber and its weight. J.Agric.Sci. (1979) 93 403-409

Yates, F., A new method of arranging variety trials involving a large number of varieties. J.Agric.Sci. (1936) 26 424-55

Yates, F., Cochran, W.G., The analysis of groups of experiments. J.Agric.Sci. (1938) 28 557-580

Yates, F., The recovery of inter-block information in variety trials arranged in three dimensional lattices. Ann.Eugen. (1939) 9 136-56

Yates, F., The recovery of inter-block information in balanced incomplete block designs. Ann.Eugen. (1940) 10 317-25

ERRATA

Replace lines 15-16 on page 21 'the between plant variation as low as possible.' by 'coefficient of variation within a plot low.'

Page 23 replace property (iii), lines 3-5 by:

(iii) given two varieties that are i associates, the number of varieties that are j^{th} associates of the first variety and k^{th} associates of the second variety is the same no matter which pair of i associates is taken first.

Page 37 After Section 5.8 insert: Here we consider critical percentage differences which give a 2.5% probability of accepting a test variety when the true difference between the test variety and the mean of two control varieties is zero.

$$d(0.05) = 1.96s \quad \text{where } s = 100(3V/2)^{\frac{1}{2}}/(\text{mean yield})$$

V is the variance of a variety mean over all centres and years.

Page 38, 6 lines from the bottom insert: Variety trials generally use many centres in few years, so the behaviour of the critical differences in the lower portion of Table 16 is important.

Page 39, 5.11 after the end of the first sentence insert:

An acceptance probability is the probability of accepting a variety which yields a given percentage of a control variety's yield.

Page 55, line 5 delete '(Sprent, 1969).' and insert,

(Sprent, page 24 1969). This test has a t distribution conditional on the $\hat{I}_j$.'

Page 71 replace the page by the new page opposite.

The method of least squares requires;

$\sum_i \sum_j (y_{ij} - \mu_i - \beta_i I_j \theta - \gamma_i \xi_j \omega)^2$ to be minimised.

The Normal equations are:

$$\sum_j (y_{ij} - \mu_i - \beta_i I_j \theta - \gamma_i \xi_j \omega) = 0 \quad (i)$$

$$\theta \sum_i \beta_i (y_{ij} - \mu_i - \beta_i I_j \theta - \gamma_i \xi_j \omega) = 0 \quad (ii)$$

$$\sum_j I_j (y_{ij} - \mu_i - \beta_i I_j \theta - \gamma_i \xi_j \omega) = 0 \quad (iii)$$

$$\omega \sum_i \gamma_i (y_{ij} - \mu_i - \beta_i I_j \theta - \gamma_i \xi_j \omega) = 0 \quad (iv)$$

$$\sum_j \xi_j (y_{ij} - \mu_i - \beta_i I_j - \gamma_i \xi_j \omega) = 0 \quad (v)$$

and lead to estimates of the form:

$$I_j \theta = \sum_i \beta_i (y_{ij} - \mu_i - \gamma_i \xi_j \omega)$$

$$= \sum_i \beta_i (y_{ij} - y_{i.})$$

$$\text{and } \beta_i \theta = \sum_j I_j (y_{ij} - \gamma_i \xi_j \omega)$$

$$\text{so } \beta_i \theta^2 = \sum_i \sum_j \beta_i (y_{ij} - y_{i.})(y_{ij})$$

$$\text{Likewise } \gamma_i \omega^2 = \sum_i \sum_j \gamma_i (y_{ij} - y_{i.})(y_{ij}) .$$

$$\text{If } t_{ik} = \sum_j (y_{ij} - y_{i.})(y_{kj} - y_{k.}) \text{ then}$$

$$\beta_i \theta^2 = \sum_k \beta_k t_{ik}$$

$$\gamma_i \omega^2 = \sum_k \gamma_k t_{ik} .$$

Hence θ^2 and ω^2 are latent roots of $\underline{T}$.

1 JAN 1989