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The impact of some agronomic factors on the variability of potato tuber size distribution

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Summary

Using data from a wide range of experiments, the effects of some agronomic factors on the variability of the tuber size distribution were calculated. The factors studied were nitrogen (N), phosphorus (P), potassium (K), seed-tuber planting density, physiological age, date of harvest, seed-tuber weight, irrigation, cultivar and site of production.

There were significant effects of N, date of harvest, cultivar and site of production on the variability of the tuber size distribution measured as the coefficient of variation (CV) of tuber size. The CV increased with higher levels of applied N and with later harvesting. The largest effect, but one that was unquantifiable, was that of site of production.

These results demonstrate that the uniformity of tuber size distribution can vary and suggest that work to understand the reasons for this would be valuable.

Introduction

The literature contains many examples of the effects of various husbandry factors on the yield of tubers in different size grades, though the majority of data sets contain few tuber sizes. Notable exceptions to this have been Hanley et al. (1965) who plotted the yields in up to 10 grades over time, Jarvis & Shotton (1968) who showed histograms of yield in 5 size grades and Hide & Lapwood (1978) who produced diagrams showing trends of tuber size distribution. Some papers specifically refer to the 'tuber size distribution' (Schepers, 1975; Cother & Cullis, 1985) yet only present the yield in 2 or 3 weight or size grades.

Attempts have been made to describe the distribution mathematically (Pohjonen & Paatela, 1976; Sands & Regel, 1983) but both these models are based on grading by tuber weight rather than tuber size, which is how the majority of tubers are graded in the UK. Marshall (1986a) has used the technique of Sands & Regel (1983) to measure the relative variability (and hence the uniformity) of a sample of tubers as the ratio of σ, a measure of the spread of tuber weight, to μ, a measure of average tuber weight. MacKerron et al. (1988) used the same technique, converting weights to diameters in order to have practically relevant data. They reported no effect of drought on the relative variability of the distribution; its main effect was on total yield and hence mean tuber size. Marshall & Thompson (1986) found that σ was linearly related to μ and that nitrogen application, irrigation and time of harvest did not affect this relationship.

Uniformity (lack of variability) to the grower tends to mean more yield in the size grade that he or she can sell, and it is therefore relevant to work directly in tuber size. The technique developed by Travis (1987) for tubers in size-limited grades is particularly appropriate. He showed that the distribution of yield in size grades was approximately normal with mean (μ) and variance (σ^2).

This paper applies Travis's technique to many experimental data sets and then studies the effects of agronomic factors on the variability of tuber size distribution, including the impact of the number of tubers formed on the coefficient of variation of tuber size. The aim of the paper is to establish both whether and how agronomic factors affect the variability of tuber size distribution.

Materials and methods

The data used in this paper were taken from a wide range of experiments conducted by staff from the Cambridge University Farm. Table 1 shows the factors examined, the number of experiments used to provide data, the spread of experiments over time and the range of treatments. The following factors were studied: nitrogen (N), phosphorus (P), potassium (K), seed-tuber planting density, physiological age, date of harvest, seed-tuber weight, irrigation, cultivar and site of production.

When experiments were harvested, potatoes were graded into at least 5 size grades, making the data suitable for analysis according to the technique described by Travis (1987). This involved describing the size distribution of potatoes (measured as the

Table 1. Information on experiments used to provide data for analyses.

Set	Agronomic factor tested	Number of expts	Range of years	Treatment range
1	Nitrogen (N)	9	1989-1991	0-300 kg/ha
2	Phosphorus (P)	5	1989-1990	0-100 kg/ha
3	Potassium (K)	5	1989-1990	0-300 kg/ha
4	Seed-tuber planting density	45	1981-1985	12000-175000 seed tubers/ha
5	Physiological age	4	1981-1984	0-1200 day-degrees > 4° C
6	Harvest date	4	1984-1985	191-271 day number (Jan 1 = 1)
7	Seed-tuber weight	44	1981-1985	35, 70, 105 g
8	Water	3	1984-1989	Non-irrigated Irrigated
9	Cultivar	16	1982-1991	Record, Maris Piper, King Edward, Estima, Pentland Squire
10	Site of production	4	1982	Yorkshire, Lincolnshire, Cambridgeshire, Hampshire.

weight in discrete size grades) by 2 parameters: the grade size containing the greatest proportion of the yield (μ) and a measure of the spread of yield across size grades (σ).

Results

Since σ is positively related to μ (Marshall, 1986b; Marshall & Thompson, 1986) we used the coefficient of variation (CV), calculated as $\sigma/\mu \times 100$ (%), as a more stable measure of variability. In order to check that CV was an appropriate statistical measure, analyses of variance were performed on 10 experiments selected at random from those available, and residual values were plotted against both fitted values and half-normal quantiles. The residual plots suggested that the CV was normally distributed and was therefore acceptable as a measure of variability for use in subsequent analyses.

The potential importance to the grower of changes in the CV are illustrated in Table 2, which shows the percentage of tubers within the saleable size range 40 – 80 mm for a range of potential tuber size distributions. These had arbitrarily chosen values of μ varying from 50 to 70 mm, and a CV of 14 – 26 %. The ranges of CV were chosen to cover those observed in the experiments studied. With all values of μ, increasing values of CV reduced the yield in the saleable grade 40 – 80 mm. For example, with a μ value of 60 mm an increase of CV from 18 to 24 % reduced the saleable yield by 10.1 %.

Data from all the experiments within each set (Table 1) were analysed together because standard errors of the means within each set were of similar magnitude.

Regression analyses. For sets 1 to 6 with quantitative treatment levels, linear models were fitted to all the available data to determine whether the treatments affected CV and if so whether positively or negatively. However, there were large effects of individual experiments which had to be taken into consideration.

With N (set 1), a model fitting separate intercepts for each experiment accounted for 39.4 % of the variance of CV, which was increased to 68.2 % after adding the effect of N by fitting lines for each experiment with a separate intercept and a common slope. This relationship was significant with the CV increasing at higher levels of applied N. Fig. 1 shows all of the available data, with standard errors of the means and the slope of the model using the mean intercept value. The fitted line $y = 0.004865x + 20.1$, is plotted, where 20.1 is the mean intercept for the experiments included in the model.

Table 2. Percentage yield of tubers graded 40-80 mm for a range of values of μ and CV.

μ (mm)	CV (%)						
	14	16	18	20	22	24	26
50	92.3	89.4	86.6	84.0	81.5	79.1	76.9
55	97.4	95.4	92.9	90.2	87.3	84.3	81.3
60	98.3	96.3	93.6	90.4	87.0	83.5	80.0
65	94.7	91.7	88.4	84.8	81.3	77.7	74.3
70	84.5	81.0	77.8	74.6	71.6	68.7	65.9

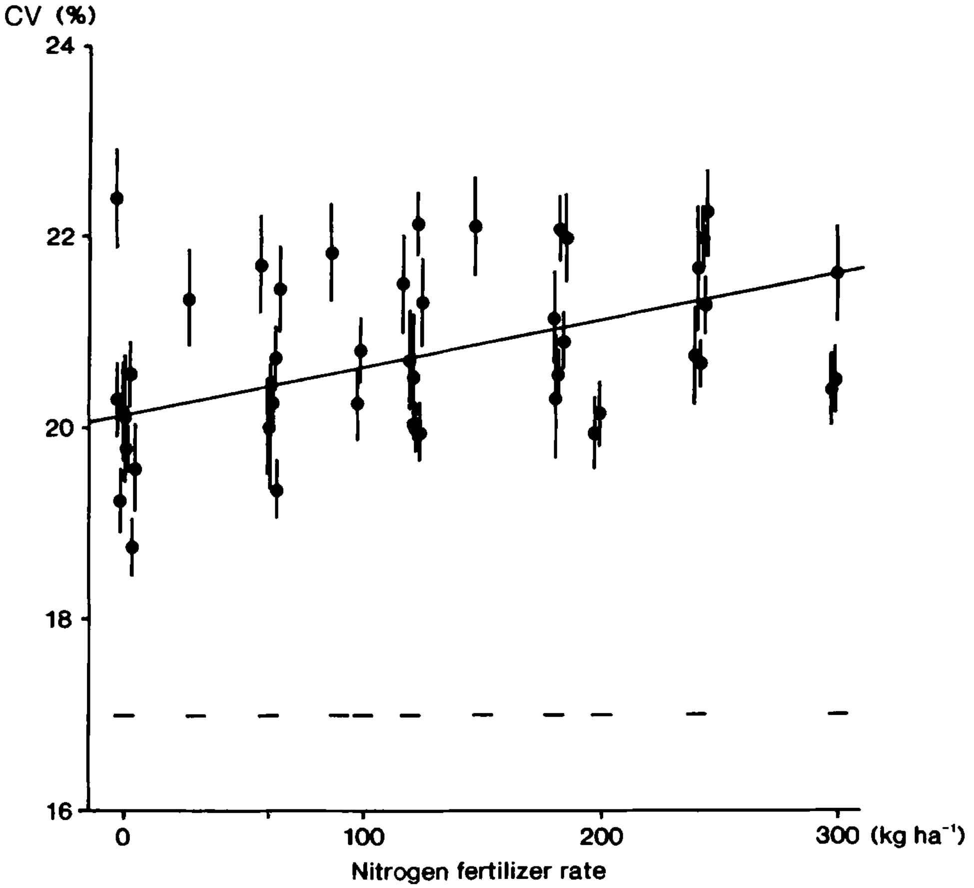

Fig. 1. The effect of level of N application on CV. Values are plotted in groups, shown by horizontal bars, for each level of N. Vertical bars represent standard errors of the means.

When similar analyses were conducted for P (set 2) and K (set 3) there was no effect of either nutrient on CV. With P, a model fitting a separate intercept for each experiment accounted for 93.4% of the variance of the CV, but this was not increased by adding a term for P.

The effect of within-row spacing, expressed as seed-tuber planting density (set 4) on CV, showed that a model fitting lines with a separate intercept and a common slope for each experiment accounted for 69.1% of the variance. As the seed-tuber planting density increased the CV decreased slightly, but this effect was not significant.

Fitting a model to physiological age (set 5), measured in day-degrees > 4 °C from the appearance of the first sprout to planting, showed no effect of physiological age on CV. However, the effects of harvest date (set 6), measured as days from planting to harvest, were significant in Expts 1-4. A linear model with different intercepts for each experiment accounted for 84.6% of the variance in CV, with later harvests resulting in a higher CV. Fig. 2 shows the data values with standard errors of the means and the fitted slope for the mean intercept. The fitted line y = 0.02822x + 17.8, is plotted, where 17.8 is the mean intercept for the 4 experiments.

There was no effect on the fit of any of the 6 data sets by including a term for the total number of daughter tubers harvested, indicating that tuber number did not account for any of the variation in CV between treatments and experiments.

The data for cultivars (set 9) showed that a range of CVs was possible within any one cultivar, as follows: cv. Estima, with CVs ranging from 20.2-23.0%, cv. King Edward (17.6-24.4%), cv. Maris Piper (16.5-24.0%), cv. Pentland Squire (20.0-

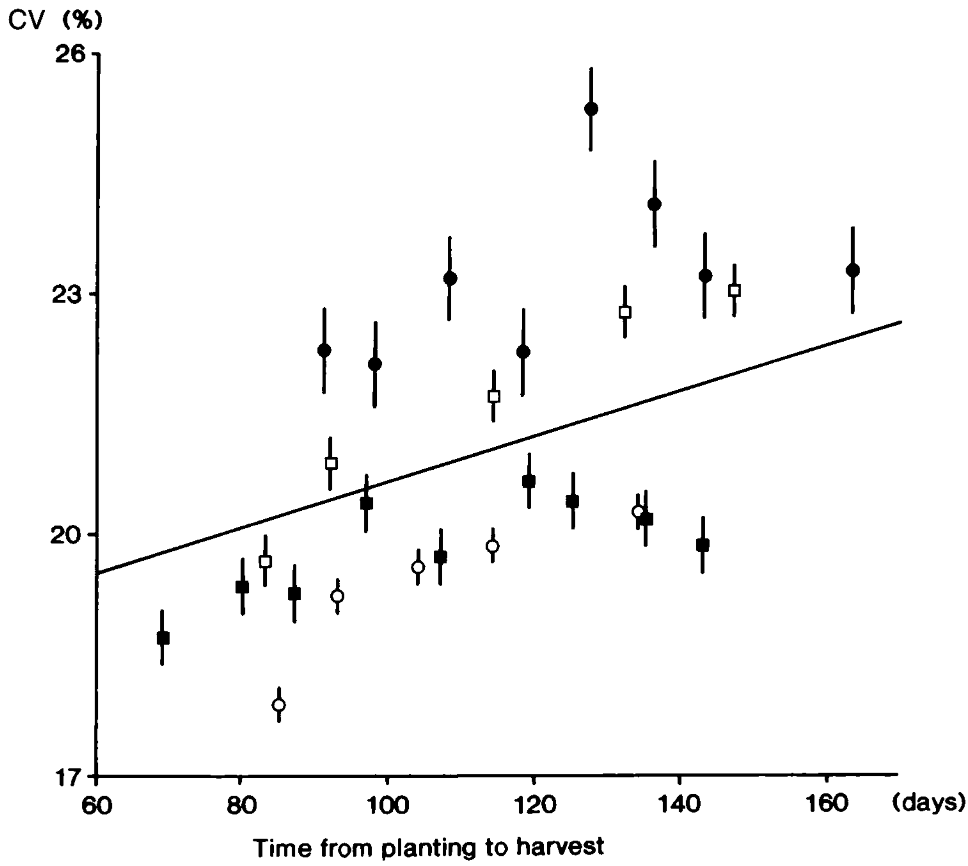

Fig. 2. The effect of harvest date on CV for Expts 1 ● and 2 □; at Cambridge in 1984 and 1985 respectively, and Expts 3 ■; and 4 ○ at Swaffham Prior, Cambridgeshire in 1984 and 1985 respectively. Vertical bars represent standard errors of the means.

22.7%) and cv. Record (15.0-19.8%). It was noticeable that cvs Estima and Pentland Squire had a much smaller range of CV than the other cultivars. After accounting for the effect of the different experiments, a regression model showed that for cv. Record the CV was significantly lower than in the other cultivars.

Analyses of variance. With seed-tuber weight (set 7), although there were 93 data values available for comparison, only 3 tuber weights were used (35, 70 and 105 g) and the distribution of individual values of the CV at each of these weights was not normal. Regression analysis was therefore inappropriate, and a non-parametric test (Siegel, 1956), i.e. the Kruskal-Wallis one-way analysis of variance, was applied to the data. However, there was no significant effect ($P < 0.05$) of seed-tuber weight on CV. The mean CVs for seed tubers weighing 35, 70 and 105 g were respectively 18.7, 20.6 and 19.5%.

With qualitative treatments of irrigation (set 8) and site (set 10), linear models were again inappropriate, and so non-parametric tests were applied to the data. For effects of irrigation, data were taken from 3 experiments where a clear comparison could be made between treatments where irrigation was applied and where it was not. A Mann-Whitney U test (Siegel, 1956) showed that there was no significant difference ($P = 0.05$) between CVs from irrigated treatments (respectively 18.2, 18.0 and 23.0%) and non-irrigated treatments (respectively 18.7, 17.4 and 22.7%).

The final qualitative comparison was between sites, and the data used for this came from 4 similar trials in the same year but at different sites. Fig. 3 shows data for 4 varieties at each site, and a Kruskal-Wallis one-way analysis of variance revealed that there was a significant effect ($P<0.01$) of site.

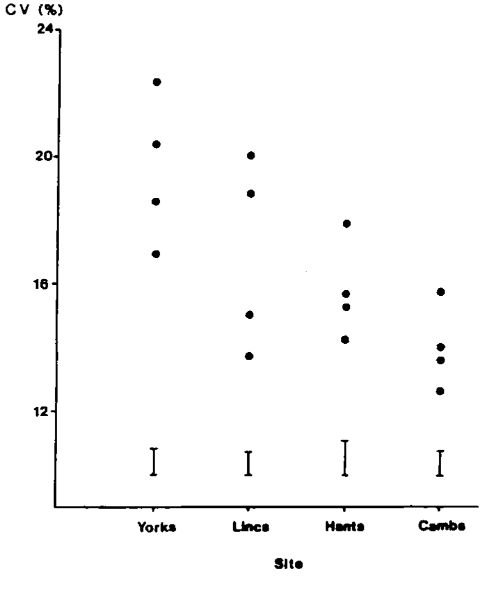

Fig. 3. The effect of site on CV. Vertical bars represent standard errors of the means. Sites in Yorkshire (Yorks), Lincolnshire (Lincs), Hampshire (Hants) and Cambridgeshire (Cambs).

Discussion

If only 1 tuber size grade were important for marketing potatoes every year then all growers could concentrate on maximising the yield in that grade. However, many size grades are important and requirements can change from year to year so that experimental information on the distribution of tuber sizes may not be comparable unless identical riddle sizes are used. In the UK the situation has been complicated further by the change from imperial to metric size grades. On the face of it this makes data from experiments graded imperially of no use in determining requirements for crops that are now graded metrically. However, if the potato size distribution can be described mathematically it can be used on data with different size grades and units to describe variability and hence uniformity. Thus the technique of Travis (1987) provides a strong unifying tool for making maximum use of otherwise disparate data from a range of sources, expressed in different units.

The term 'variability' of the tuber size distribution tends to be used loosely in practice. This paper measures variability as the coefficient of variation (CV) of tuber size, and shows how large differences in CV can occur between treatments and experiments. Table 2 demonstrates how important such effects can be in affecting the yield in saleable size grades. Two crops may have the same total yield, but if they have different levels of variability then saleable yields and financial returns will differ. A difference of 2% in CV can alter the yield by up to 3.5% (Table 2). This effect can be further compounded when different size fractions have different values; for example tubers graded 60-80 mm may be worth twice as much as those graded 40-60 mm.

The results from the data available here show that N, date of harvest, site and cultivar influenced the variability of tuber size, while P, K, seed-tuber spacing, seed-tuber weight, physiological age and irrigation had no effect. This lack of effect of irrigation agrees with MacKerron et al. (1988), who suggested that drought would not influence the relative variability (CV) of the distribution of tuber sizes except where it influenced the number of tubers. MacKerron et al. (1988) found that the CV was inversely related to the number of tubers set, but in none of our analyses were we able to demonstrate that the total number of tubers affected the CV. We suspect that the influence of tuber number on the variability of size distribution is more complex, as suggested by Fig. 4. This shows the CV plotted against the total number of daughter tubers for the four experiments in set 6, referred to as Expts 1 – 4. Each experiment produces its own compact grouping of data, with no apparent overall relationship. Within Expt 1 there was a positive response of CV to total tuber number, while within Expt 2 the reverse was true. Struik et al. (1991) have already drawn attention to the fact that both positive and negative relationships between CV and tuber number can exist. We suggest that changes in the total tuber number only affect μ, and that the position of the tuber on the stem and the time period over which tubers form are more likely to influence the variability in tuber size.

It is interesting that higher levels of N increase the CV but that P and K have no effect. Neither closer spacing of seed tubers nor the use of heavier seed tubers affected the CV. This suggests that effects of stem clumping (resulting from heavier seed) on variability are not inherently different from those of closer spacing, which alter the rectangularity of spacing.

Struik et al. (1990) have summarized the physiological factors affecting the tuber

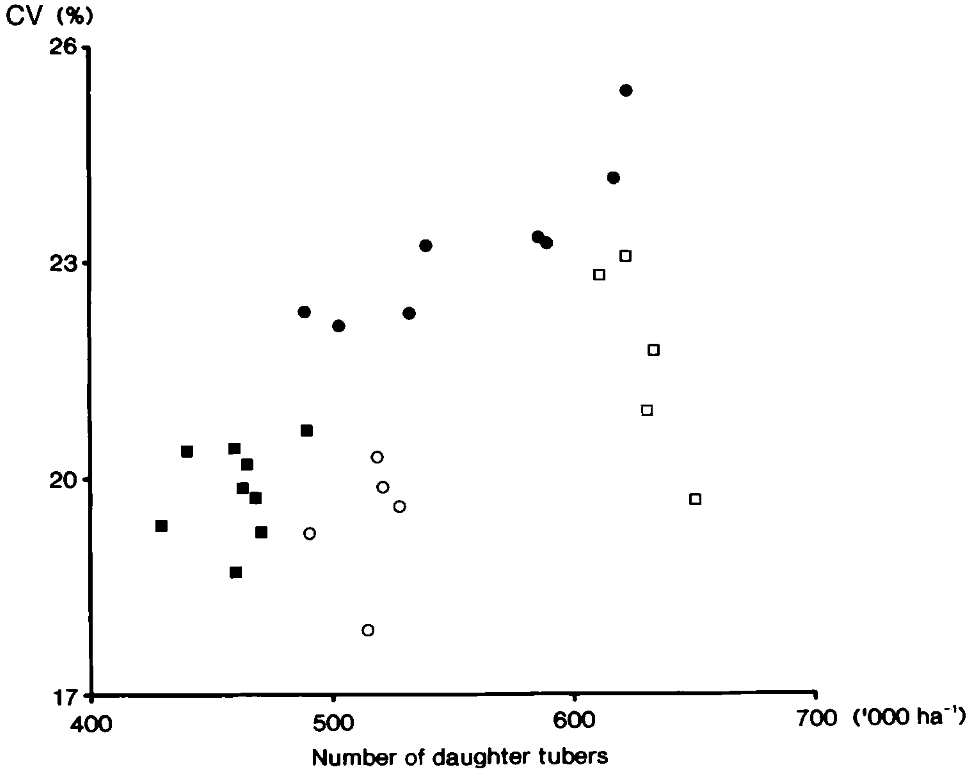

Fig. 4. The relationship between CV and total number of daughter tubers harvested for Expts 1 ● and 2 □; at Cambridge in 1984 and 1985 respectively, and Expts 3 ■; and 4 ○ at Swaffham Prior, Cambridgeshire in 1984 and 1985 respectively.

size distribution within a crop. This paper makes no attempt to study these components, but they must nevertheless be implicated in the large effects of experiment and site found in the analyses. The merit of the work presented here is that although it makes relatively crude assessments of agronomic factors, it combines data from a broad spectrum of situations. It is therefore more likely to apply to farm crops in general than to individual relationships found in specific situations. Our aim has been to demonstrate whether and how some agronomic factors affect the variability of tuber size distribution.

Effects on uniformity have important financial consequences, and understanding the causal processes of tuber initiation and retention must be improved if maximum profit is to be achieved. The large amount of information summarized by Struik et al. (1990) is largely concerned with the effects of physiological factors, not with the causal processes, and this severely limits its interpretation. The process of tuberization and its consequences for the growth and grading of potato crops must be studied in much greater detail, so that control mechanisms influencing tuber size variability can be established. It may be that these factors need examining in controlled-environment growing rooms, applying specific environmental treatments and then determining μ and σ in order to understand precisely what controls tuber size variability.

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