Final Report

Development of seed rate recommendations for new varieties

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Report Authors:
David Firman
NIAB-CUF

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CONTENTS

1. Summary

1.1. Aims

The aims of this project were to determine the suitability of simplified systems for establishing seed rate recommendations, develop the use of systems with collaborators and to collate and describe datasets of varietal characters important for determining seed rates.

1.2. Methodology

Simple randomized block field experiments were conducted in each of three years consisting of different stocks and seed sizes of different varieties. Thirteen common varieties were included in all years and one variety (Vales Sovereign) included in 2011 only was dropped from the project so that datasets were assembled for a total of 17 varieties. Mean seed tuber weights were recorded for each stock and size. The number of stems, tubers and graded yield were obtained from harvests taken from these experiments and the mean tuber size and tuber shape calculated. Complementary data on numbers of stems, numbers of tubers and graded yield from collaborators' experiments and from commercial crops were collected and collated alongside the data from the field experiments.

The combined datasets were analysed to calculate key relationships and parameters which affect seed rate requirements. These included the relationships between the number of tubers and stems, relationships between the number of stems per seed tuber and seed tuber weight, effect of seed age on the number of stems per seed tuber and tuber shape. These parameters were used to derive provisional seed rate recommendations for the varieties included in the study using a system adapted from previous work.

1.3. Key findings

Simple experiments conducted over three seasons can provide sufficiently consistent data to enable calculation of preliminary seed rates for new varieties for standard-aged seed stocks. Determining the effect of seed age on seed rates is not easily achieved using readily available seed stocks and documentation and requires dedicated identification or production of seed of contrasting age combined with a

specific experimental approach. Relatively little data suitable for calculating key parameters for deriving seed rates are routinely collected by organisations with interests in introducing new varieties. Whilst the simple system for deriving new seed rates should be more effective than existing approaches of basing recommendations on existing varieties, this new approach cannot be adopted without resources being dedicated to provide the required information. The most reliable seed recommendations from this project can be expected to be for the varieties Casablanca, Innovator, Jelly, Markies, Perline, Saphire and Sylvana for which fairly comprehensive datasets were collated whilst recommendations for the other varieties studied would benefit most from further development work.

1.4. Practical recommendations

Organisations interested in the effective introduction of new varieties should ensure systems are in place to capture accurate data on seed and ware crops which can be used to derive and adapt seed rate recommendations for these varieties. Data on the emergence date of seed crops should be routinely collected and documented so that the effect of seed age can be quantified and, where appropriate, accounted for in recommendations. Given the importance of appropriate seed rates in achieving the target size distribution in crops with contrasting end markets (e.g. salads and bakers), conducting specific experiments to obtain data to calculate key variety-specific parameters affecting seed rates would be worthwhile and should form part of the process of new variety introductions.

2. INTRODUCTION

Previous research into the effects of seed age on stem production led to the development of new seed rate recommendations for Estima based on data from a series of experiments conducted over several years (Firman *et al.*, 2006). These recommendations used a mechanistic approach based on the relationship between the number of stems, seed tuber weight and seed age and subsequent experiments with additional varieties have enabled the same approach to be used to derive recommendations for these varieties. An extensive ongoing experimental programme would be required to provide recommendations for all new varieties in the same way and a system based on obtaining key variety traits without such a programme would enable a more accessible means of deriving seed rate recommendations for new varieties using similar principles.

The objective of this project was to develop a simple system for deriving recommendations that should be more effective than the commonly adopted approach of basing recommendations for new varieties on those used for existing varieties. By working with collaborators who have an interest in developing use of new varieties, the key variety traits required have been derived from all readily available data sources complemented by data from simple experiments. A database of varietal characters has been generated that can be updated to provide more reliable estimates of the characters as more datasets become available.

3. Materials and methods

3.1. Field experiments at Cambridge University Farm

For field experiments at Cambridge University Farm (CUF), collaborators were requested to source seed stocks of each variety of interest with as large a range in seed age (i.e. date of emergence of the seed crop) and seed size as possible and to supply 100 seed tubers of each combination of seed stock and seed size. On receipt at CUF, the mean tuber weight was assessed and seed held in cold store (*c*. 3 °C) until planting. For each of the varieties included, a separate randomized block experiment was planted with three replicates consisting of all available combinations of seed age and seed size, although for several stocks the seed age was not known. Thirteen common varieties were included in all years and one variety (Vales Sovereign) included in 2011 only was dropped from the project so that datasets were assembled for a total of 17 varieties. The varieties, seed ages, seed sizes and planting dates are as shown in Table 1.

Experiments were planted by hand into pre-formed ridges and each plot consisted of four 76 cm wide rows of eight plants at a within-row spacing of 30 cm. A liquid application of 200 kg N/ha followed by a pre-emergence herbicide application of flufenacet + metribuzin and glufosinate ammonium was applied after planting in each year.

For each experiment, a harvest of 10 guarded plants was dug from the two central rows and the number of main and secondary stems counted. The number of above-ground stems was counted for all remaining plants in each plot. Tubers were graded in 10 mm size fractions and the fresh weight and number in each size grade recorded.

3.2. Experiments at other sites

Where collaborators carried out experiments that included the varieties of interest, they were asked to provide as much relevant data as possible including seed age, seed tuber count, planting date, number of stems, numbers of tubers and graded yield.

3.3. Field crops

Collaborators were provided with protocols to facilitate collection of key data on field crops of varieties of interest. Cropping details including seed age, seed count and date of planting of the field crop were requested. Wherever possible, three or more replicated harvests of at least 3 m of row were dug and the number of plants and stems and graded yield assessed. To augment data provided by collaborators, some additional crops were visited and assessed including crops forming part of other projects such as the Potato Council funded Grower Collaboration Project.

Table 1. Details of field experiments at Cambridge

Variety	Seed size (mm)	Seed count (/50kg)	Date of seed crop emergence	Date of planting
2011				
Cabaret	25x30	1872	3 Jun	13 Apr
Cabaret	35x40	1126	3 Jun	13 Apr
Cabaret	50x55	404	3 Jun	13 Apr
Cabaret	25x30	2470	24 Jun	13 Apr
Cabaret	35x40	902	24 Jun	13 Apr
Cabaret	50x55	340	24 Jun	13 Apr
Casablanca	25x30	2643	11 Jun	13 Apr
Casablanca	35x40	1273	11 Jun	13 Apr
Casablanca	50x55	469	11 Jun	13 Apr
Casablanca	25x32	2608	30 May	13 Apr
Casablanca	35x40	1247	30 May	13 Apr
Casablanca	45x55	901	30 May	13 Apr
Chicago	25x30	3084	9 Jun	13 Apr
Chicago	35x40	1238	9 Jun	13 Apr
Chicago	50x55	467	9 Jun	13 Apr
Elfe	35x45	1148		20 Apr
Elfe	45x55	432		20 Apr
Excalibur	35x45	969		13 Apr
Excalibur	45x55	564		13 Apr
Harmony	35x45	1247		15 Apr
Harmony	45x55	556		15 Apr
Harmony	55x60	362		15 Apr
Innovator	25x35	2324	1 Jun	13 Apr
Innovator	35x45	893	1 Jun	13 Apr
Innovator	45x55	517	1 Jun	13 Apr
Innovator	35x45	1005		20 Apr
Innovator	35x55	1229		20 Apr
Jelly	35x45	1047		13 Apr
Jelly	45x55	528		13 Apr
Jelly	30x38	1350		13 Apr
Jelly	38x42.5	926		13 Apr
Jelly	42.5x50	628		13 Apr
Marabel	35x45	1192		20 Apr
Marabel	45x55	623		20 Apr
Marabel	35x55	880		20 Apr
Markies	30x35	1546	4 Jun	13 Apr
Markies	35x45	886	4 Jun	13 Apr
Markies	45x55	582	4 Jun	13 Apr
Melody	35x40	1399		15 Apr
Melody	45x55	426		15 Apr
Perline	25x35	2556		13 Apr
Perline	40x50	872		13 Apr
Piccolo Star	35x45	995		15 Apr
Piccolo Star	45x55	542		15 Apr
Piccolo Star	35x45	1339		15 Apr

Variety	Seed size (mm)	Seed count (/50kg)	Date of seed crop emergence	Date of planting
Piccolo Star	45x55	523		15 Apr
Saphire	35x40	1285		15 Apr
Saphire	50x55	496		15 Apr
Saphire	35x40	1245		15 Apr
Saphire	50x55	497		15 Apr
Saxon	25x30	3296	7 May	15 Apr
Saxon	35x40	1322	7 May	15 Apr
Saxon	50x55	511	7 May	15 Apr
Saxon	25x30	3202	1 Jun	15 Apr
Saxon	35x40	1369	1 Jun	15 Apr
Saxon	50x55	486	1 Jun	15 Apr
Sylvana	35x45	1175		15 Apr
Sylvana	45x55	654		15 Apr
Vales Sovereign	35x45	1005		15 Apr
Vales Sovereign	45x55	489		15 Apr
Vivaldi	45x55	744		20 Apr
2012				
Harmony	35-45	912		18 Apr
Cabaret	25-35	1477		16 Apr
Cabaret	50-55	358		16 Apr
Cabaret	25-35	1352		16 Apr
Cabaret	50-55	349		16 Apr
Casablanca	25-35	2099		16 Apr
Casablanca	50-55	398		16 Apr
Casablanca	25-35	1720		16 Apr
Casablanca	50-55	518		16 Apr
Chicago	35-45	853		16 Apr
Chicago	55-60	346		16 Apr
Chicago	35-45	999		16 Apr
Chicago	55-60	348		16 Apr
Elfe	<35	2008		16 Apr
Elfe	35-45	1060		16 Apr
Elfe	45-55	722		16 Apr
Elfe	<35	1612		16 Apr
Elfe	35-45	1118		16 Apr
Elfe	45-55	634		16 Apr
Excalibur	25-30	1761		16 Apr
Excalibur	30-45	900		16 Apr
Excalibur	50-55	384		16 Apr
Harmony	45-55	490		18 Apr
Harmony	35-45	1008		18 Apr
Harmony	45-55	478		18 Apr
Innovator	35-45	855	24 May	18 Apr
Innovator	45-55	484	24 May	18 Apr
Innovator	35-45	907	17 Jun	18 Apr
Innovator	45-55	490	17 Jun	18 Apr
Jelly	25-30	2969		16 Apr

Variety	Seed size (mm)	Seed count (/50kg)	Date of seed crop emergence	Date of planting
Jelly	30-45	1017		16 Apr
Jelly	50-55	549		16 Apr
Marabel	<35	2163		16 Apr
Marabel	35-45	1300		16 Apr
Marabel	45-55	647		16 Apr
Marabel	<35	1505		16 Apr
Marabel	35-45	1139		16 Apr
Marabel	45-55	653		16 Apr
Markies	35-45	894	31 May	16 Apr
Markies	45-55	462	31 May	16 Apr
Markies	35-45	850	16 Jun	16 Apr
Markies	45-55	596	16 Jun	16 Apr
Melody	35-45	1002		18 Apr
Melody	45-55	486		18 Apr
Melody	35-45	918		18 Apr
Melody	45-55	466		18 Apr
Perline	30-45	1086		16 Apr
Perline	45-50	531		16 Apr
Perline	30-45	1084		16 Apr
Perline	45-50	553		16 Apr
Perline	25-30	3401		16 Apr
Perline	30-45	1288		16 Apr
Perline	50-55	504		16 Apr
Piccolo Star	35-40	777		18 Apr
Piccolo Star	50-55	511		18 Apr
Piccolo Star	25-30	2707		18 Apr
Piccolo Star	35-40	1114		18 Apr
Piccolo Star	50-55	415		18 Apr
Saphire	35-45	1200		23 Apr
Saphire	45-55	523		23 Apr
Saphire	35-40	1056		23 Apr
Saphire	50-55	558		23 Apr
Saxon	25-35	2109		16 Apr
Saxon	50-55	447		16 Apr
Saxon	25-35	2477		16 Apr
Saxon	50-55	503		16 Apr
Vivaldi	25-35	2801		16 Apr
Vivaldi	35-45	882		16 Apr
Vivaldi	45-55	468		16 Apr
Vivaldi	25-35	1862		16 Apr
Vivaldi	35-45	861		16 Apr
Vivaldi	45-55	488		16 Apr
2013				
Cabaret	25-35	1608		17-Apr
Cabaret	55-60	285		17-Apr
Cabaret	25-35	1699		17-Apr
Cabaret	50-55	444		17-Apr

Variety	Seed size (mm)	Seed count (/50kg)	Date of seed crop emergence	Date of planting
Casablanca	25-30	2300	12 Jun	16-Apr
Casablanca	50-55	417	12 Jun	16-Apr
Casablanca	25-30	2552	24 Jun	16-Apr
Casablanca	50-55	500	24 Jun	16-Apr
Casablanca	35-45	812		16-Apr
Casablanca	45-55	441		16-Apr
Casablanca	35-45	1335		16-Apr
Casablanca	45-55	518		16-Apr
Chicago	25-35	1946		17-Apr
Chicago	50-55	586		17-Apr
Chicago	25-35	1570		17-Apr
Chicago	50-55	532		17-Apr
Elfe	35-45	1009		15-Apr
Elfe	45-55	566		15-Apr
Elfe	35-45	640		15-Apr
Elfe	45-55	541		15-Apr
Harmony	35-45	1057		29-Apr
Harmony	45-55	532		29-Apr
Innovator	25-30	1834	12 Jun	17-Apr
Innovator	50-55	587	12 Jun	17-Apr
Innovator	25-30	2142	24 Jun	17-Apr
Innovator	50-55	463	24 Jun	17-Apr
Jelly	30-45	1233	19 Jun	17-Apr
Jelly	45-50	628	19 Jun	17-Apr
Jelly	50-55	463	19 Jun	17-Apr
Jelly	30-45	1014	1 Jul	17-Apr
Jelly	45-50	507	1 Jul	17-Apr
Jelly	50-55	457	1 Jul	17-Apr
Marabel	35-45	1114		15-Apr
Marabel	45-55	612		15-Apr
Marabel	35-45	1045		15-Apr
Marabel	45-55	611		15-Apr
Markies	25-30	1735	16 Jun	17-Apr
Markies	50-55	423	16 Jun	17-Apr
Markies	25-30	1653	30 Jun	17-Apr
Markies	50-55	463	30 Jun	17-Apr
Melody	35-45	958		29-Apr
Melody	45-55	511		29-Apr
Perline	<35	2451		17-Apr
Perline	35-45	1186		17-Apr
Perline	45-50	727		17-Apr
Perline	50-55	540		17-Apr
Piccolo Star	25-35	2262		17-Apr
Piccolo Star	25-35	1764		17-Apr
Piccolo Star	50-55	400		17-Apr
Saphire	25-35	2793		17-Apr
Saphire	25-35	2183		17-Apr

Variety	Seed size (mm)	Seed count (/50kg)	Date of seed crop emergence	Date of planting
Saphire	50-55	486		17-Apr
Vivaldi	35-45	853		15-Apr
Vivaldi	45-55	500		15-Apr
Vivaldi	35-45	883		15-Apr
Vivaldi	45-55	511		15-Apr

3.4. Analysis

3.4.1. Overview

The data were collated and analysed to estimate the key varietal attributes required for establishing seed rate recommendations as listed in Table 2. As not all datasets included all the necessary information, subsets of data were used for estimating each of the attributes as appropriate. Although using the number of tubers per stem (TPS) at a given stem density (e.g. 100 000/ha) and change in number of tubers per stem with change in stem density (cTPSd) can enable a relatively simple estimation of stem populations required for particular combinations of tuber yield and mean tuber size, it was not always satisfactory to use these two parameters to compute a solution. An alternative approach of fitting a logarithmic curve to the relationship between tuber populations and stem populations, whilst requiring a more comprehensive dataset, was found to be more suitable. From this fitted curve, two additional parameters, the slope and constant of the logarithmic curve (TSs and TSc, respectively) were derived. For fitting the logarithmic curve and for establishing all parameters except the tuber shape constant, only spreadsheet software (Microsoft Excel 2010 with Analysis ToolPak add-in) was used in order that the system may be readily applied without requiring specialist software or computing expertise.

Genstat software was used to fit a normal distribution to grading data to calculate mean tuber size in order to estimate the tuber shape constant. The extent to which qualitative descriptions of tuber shape (e.g. long, oval round) might be used to provide an estimate of the tuber shape was examined by comparing values derived for the tuber shape constant with published descriptions of tuber shape.

To estimate the number of stems per seed tuber (SPT), change in number of stems per seed tuber with seed weight (cSPTw) and change in stems per tuber with seed age (cSPTa), multiple linear regression was used to calculate the relationship between the number of stems per plant and the two variables of mean seed weight and seed age. Where seed age was known for a large proportion but not all of the stocks, seed with no age information was included in the regression but assumed to be of a standard age of 318 days. Where limited or no information on seed age was available, seed age was effectively omitted from the regression.

Data from all sources (field experiments, collaborators experiments and commercial crops) were combined and included in the analysis but a small number of datasets supplied by collaborators which on initial analysis were found to be extreme outliers were excluded. Each collated datapoint consisted of the mean value from all replicate plots of a treatment in an experiment or the mean of all replicate samples in a commercial crop sample.

Once the parameters were calculated, these were used to calculate seed rates for seed tubers of defined weight for target combinations of mean tuber size and yield through a stepwise process. This process involved calculating first the tuber population, then the stem population. The seed rate required to establish this stem population was then calculated from the relationship between seed tuber weight and stem production for standard aged seed and this could then be adjusted to account for seed age if appropriate where effects of seed age on stem production had been established.

Table 2. Characters influencing seed rate requirements and definition or states proposed for practical use

Character	Definition or state
Number of tubers per stem (TPS)	Stem density of 100 000/ha
Change in number of tubers per stem with change in stem density (cTPSd)	Per 50 000 stems (from a stem density of 75 000 to 125 000/ha) †
Number of stems per seed tuber (SPT)	Seed weight of 50 g. Seed age‡ of 318 days
Change in number of stems per seed tuber with seed weight (cSPTw)	Per 100 g (from a seed weight of 20 to 120 g). Seed age of 318 days
Change in stems per tuber with seed age (cSPTa)	% per month (from a seed age of 288 to 318). Seed weight of 50 g
Tuber shape constant (k)	$\dfrac{mean\ tuber\ size\ (mm)}{\left(\dfrac{yield\ (t/ha)}{number\ of\ tubers\ (000/ha)}\right)^{\frac{1}{3}}}$

† For some purposes, a different range may be adopted e.g. 150 000-250 000 stems for small tuber production.

‡ Seed age is defined as the interval from emergence of seed crop to replanting of ware crop.

3.4.2. Calculation of parameters for seed rates

3.4.2.1. Relationship between numbers of tubers and stems

The relationship between numbers of tubers and stems was analysed to determine the slope and constant of the logarithmic curve (TSs and TSc, respectively) from which TPS and cTPSd were calculated. Whilst TPS and cTPSd can be used directly to enable a relatively simple estimation of stem populations for particular combinations of tuber yield and mean tuber size, calculation using TSs and TSc is relatively straightforward and more suitable so it is proposed TPS and cTPSd are only used as indicators of the differences between varieties in the relationship between numbers of tubers and stems for which they are more informative than the parameters of the logarithmic curve. The relationship between stem and tuber populations for some varieties may be better described over a wide range of values by other curves but the logarithmic curve is generally suitable over the range of values used for calculating seed rates and is more readily fitted using Microsoft Excel than more complex alternatives.

To fit the curve, data from all datasets for which paired data for the number of tubers and number of stems was available was first collated in a standard format in columns of a spreadsheet. The number of main stems (or above-ground stems if secondary stems were not distinguished) was converted from the raw data to populations in thousands per ha accounting for the sample area and listed in one column. Similarly the numbers of tubers (in almost all cases > 10 mm but some data for tubers > 20 mm were included) was converted to populations in thousands per ha and listed alongside. Data from these two columns were then selected and a ‘scatter chart’ created with the stem population (000/ha) as the x-axis and tuber population (000/ha) as the y-axis. A logarithmic trendline was then fitted to all data in the chart and the slope (TSs) and constant (TSc) of the equation (Equation 1) displayed on the chart extracted. Using this equation, TPS and cTPSd were calculated (Equation 2 and Equation 3, respectively).

Equation 1

$$y = TSs \times \ln(x) + TSc$$

$$Where\ y\ is\ tuber\ population\ (000\ per\ ha) and\ x\ is\ stem\ population\ (000\ per\ ha)$$

Equation 2 TPS

$$TPS = \frac{TSs \times \ln(100) + TSc}{100}$$

Equation 3 cTPSd

$$cTPSd = \frac{TSs \times \ln(75) + TSc}{75} - \frac{TSs \times \ln(125) + TSc}{125}$$

3.4.2.2. Relationship between number of stems per seed tuber and seed tuber weight and seed age

The relationship between number of stems per seed tuber and seed tuber weight and seed age was analysed to calculate SPT, cSPTw and cSPTa. The relationship between the number of stems per seed tuber and seed tuber weight for seed of the same chronological age is generally linear for seed weights within the range of normal seed sizes (25 - 55 mm, *c*. 20 – 120 g) so that a linear regression can be used to estimate the number of stems expected for seed tubers of a given weight (Firman & Daniels 2010). The relationship between the number of stems per seed tuber and seed tuber weight is affected by chronological age but the extent of the effect differs between varieties (Firman & Daniels 2010). Where separate relationships for stocks of different ages are examined, linear regressions with distinct slopes and intercepts may be found (Firman *et al*. 2006). Data derived from experiments to examine the effects of seed age can be analysed to determine the effect of age on the slope and intercept of the relationship to model the effect of age on stem production (Firman *et al*. 2006). This approach is not suitable for collated data, as collected in this project, where few data (in some cases a single datapoint) may be available for an individual seed stock (of a given age) and for which seed age is not available for some of the datapoints. To simplify the analysis of seed age for these data using only data analysis readily available in Microsoft Excel 2010 (with Analysis ToolPak add-in), multiple regression was conducted with the number of stems per seed tuber as the y-variate and seed weight and seed age as x-variates.

All datasets for which paired values for seed weight and the number of stems were available were collated in a standard form in columns of a spreadsheet with number of main stems per plant (or above-ground stems if secondary stems were not distinguished) and the seed weight in g. Where the date of emergence of the seed crop and the date of planting of the ware crop were available, the chronological age of the seed at planting was calculated as the number of days from emergence to planting and this was collated in a third column of the spreadsheet. For some datasets where the date of emergence of seed was not available but the date of herbicide application to the seed crop was known, this was used as a proxy. Where no reliable estimate of the date of seed emergence could be made a standard age of 318 days was assumed for the purposes of analysis.

Multiple linear regression was carried out using the data analysis function of Microsoft Excel 2010 (this requires the Analysis ToolPak add-in to be installed). The data analysis option was selected from the data menu toolbar and regression selected from the data analysis menu which opens up a regression menu. Within the regression menu, the range of cells containing the number of stems per plant was entered into the 'Input Y Range' box and the range of cells containing the paired values for seed tuber weight and age entered into the 'Input X Range box'. The output option of 'New Worksheet Ply' was selected (default option) then analysis was initiated by selecting the 'OK' button. The values for the intercept (I) and slopes of the two x variables seed tuber weight and age (Swt and Sage, respectively) were then extracted from the data output on the newly created worksheet tab. Where no data for age were available, Sage was estimated as 0 and the number of stems per seed tuber was estimated as a function of seed weight alone. Using these values SPT, cSPTw and cSPTa were calculated as indicated below in Equation 4, Equation 5 and Equation 6, respectively.

Equation 4 SPT

$$SPT = I + (50 \times Swt) + (318 \times Sage)$$

Equation 5 cSPTw

$$cSPTw = 100 \times Swt$$

Equation 6 cSPTa

$$cSPTa = \frac{100 \times (30 \times Sage)}{\left(I + (50 \times Swt) + (318 \times Sage)\right)}$$

3.4.2.3. *Tuber shape constant*

The tuber shape constant was calculated from data of graded tuber yields from all available sources. For each set of data, the mean tuber size was first calculated which required data of tuber weights and numbers from at least four size grades > 10 mm. Some graded yield data supplied by collaborators had insufficient grades to allow mean tuber size to be calculated accurately and were thus excluded. Datasets were collated into groups with the same size grade limits and analysed using GenStat statistical software (VSN International Limited). The distribution directive of Genstat was used to fit a normal distribution to the weights in the different size grade groups with the xdeviates option set as a variate containing the upper limits of the size grades in mm. The mean tuber size (μ) for each dataset was then extracted as the value estimated for the parameter m from the fitted distribution. For each dataset, the yield (Y, t/ha) and number of tubers > 10mm (T, 000/ha) were calculated from the graded yield data and area harvested. Using these values the tuber shape constant (k) was calculated as indicated in Equation 7 below.

Equation 7 k

$$k = \frac{\mu}{\left(\frac{Y}{N}\right)^{\left(\frac{1}{3}\right)}}$$

The mean value for k from each dataset was then collated from which the mean value for each variety was calculated.

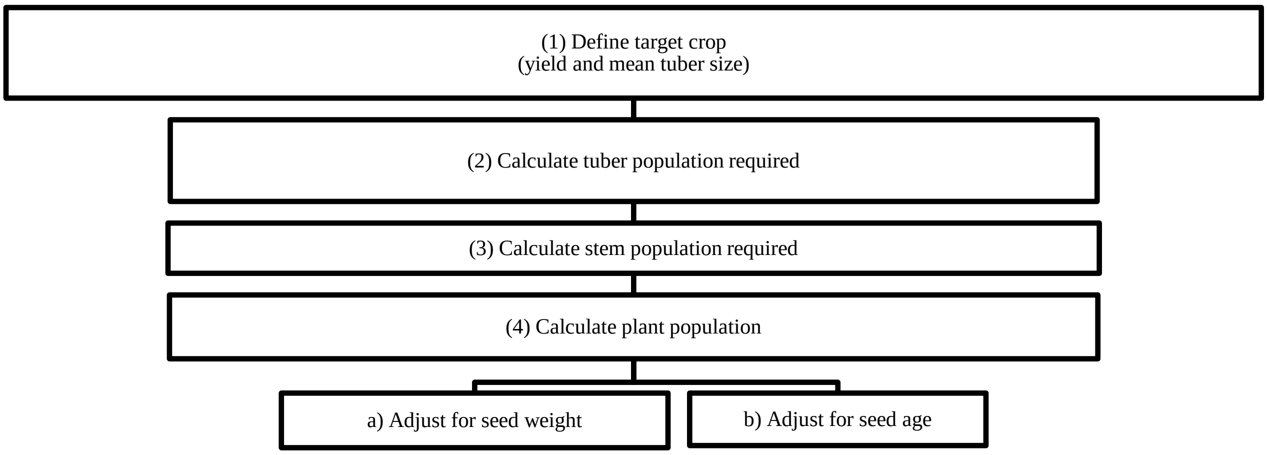
Classification of tuber shape was also collated from the European Cultivated Potato Database, British Potato Variety Database or, where not available in either database, from breeders fact sheets. The seven categories of shape used in the European Cultivated Potato Database (round, oval to round, oval, oval to long, long to oval and very long) are assigned numerical values from 1-7, respectively and these numbers were compared with the values for k calculated as above for the varieties included in this project along with 10 varieties for which seed rate recommendations and k values have previously been produced. Categories in the British Potato Variety Database or from breeders fact sheets were similarly assigned numerical values although nomenclature differed slightly. Precedence was given to values in the European

Cultivated Potato Database supplied by SASA but values from other sources were used where these were not available.

3.4.3. Calculation of seed rates

Calculation of seed rates for each of the varieties was carried out using the parameters established from the collated datasets as outlined in Figure 1 and described below.

Figure 1. Process for calculating seed rates from varietal parameters



3.4.3.1. Defining target crop

Seed rates were based on combinations of total yield (Y) and mean tuber size (μ) considered appropriate for each particular variety according to the appropriate market sector but rates appropriate for different combinations of yield and mean tuber size can be readily calculated using the process described.

3.4.3.2. Calculating the required tuber population

The tuber population (TP) required for the target crop defined was calculated using relationships between yield, mean tuber size and tuber shape established by Travis (1987) as shown in Equation 8.

Equation 8 TP

$$TP = \frac{Y}{\left(\frac{\mu}{k}\right)^3}$$

3.4.3.3. Calculating the required stem population

The stem population (SP) required for the target crop was calculated using the tuber population calculated from Equation 8 and parameters of the logarithmic curve (TSs and TSc) from the relationship established between numbers of tubers and stems (see 3.4.2.1) using Equation 9.

Equation 9 SP

$$SP = e^{\left(\frac{TP - TSc}{TSs}\right)}$$

3.4.3.4. Calculating the plant population

The plant population (PP) to achieve the stem population calculated from Equation 9 was then calculated using Equation 10 for seed of 'standard' age (i.e. 318 days from emergence to replanting) for any particular seed weight (SW in g) substituting the value of SPT obtained from Equation 4 and the value of cSPTw from Equation 5.

Equation 10 PP (weight only)

$$PP = \frac{SP}{\left(SPT + \left(cSPTw \times \frac{SW - 50}{100}\right)\right)}$$

Where reliable data on seed age were available, the plant population could be adjusted for seed age (SA in days from emergence of seed crop to replanting of ware crop) and seed weight using Equation 11 substituting the value of cSPTa from Equation 6.

Equation 11 PP (weight and age)

$$PP = \frac{SP}{\left(SPT + \left(cSPTw \times \frac{SW - 50}{100}\right)\right)\left(1 + \left(\frac{cSPTa}{100} \times \frac{SA - 318}{30}\right)\right)}$$

Using these equations, seed rate tables were produced for each of the varieties using values of mean tuber size and yield considered appropriate for general use over the normal range of seed sizes.

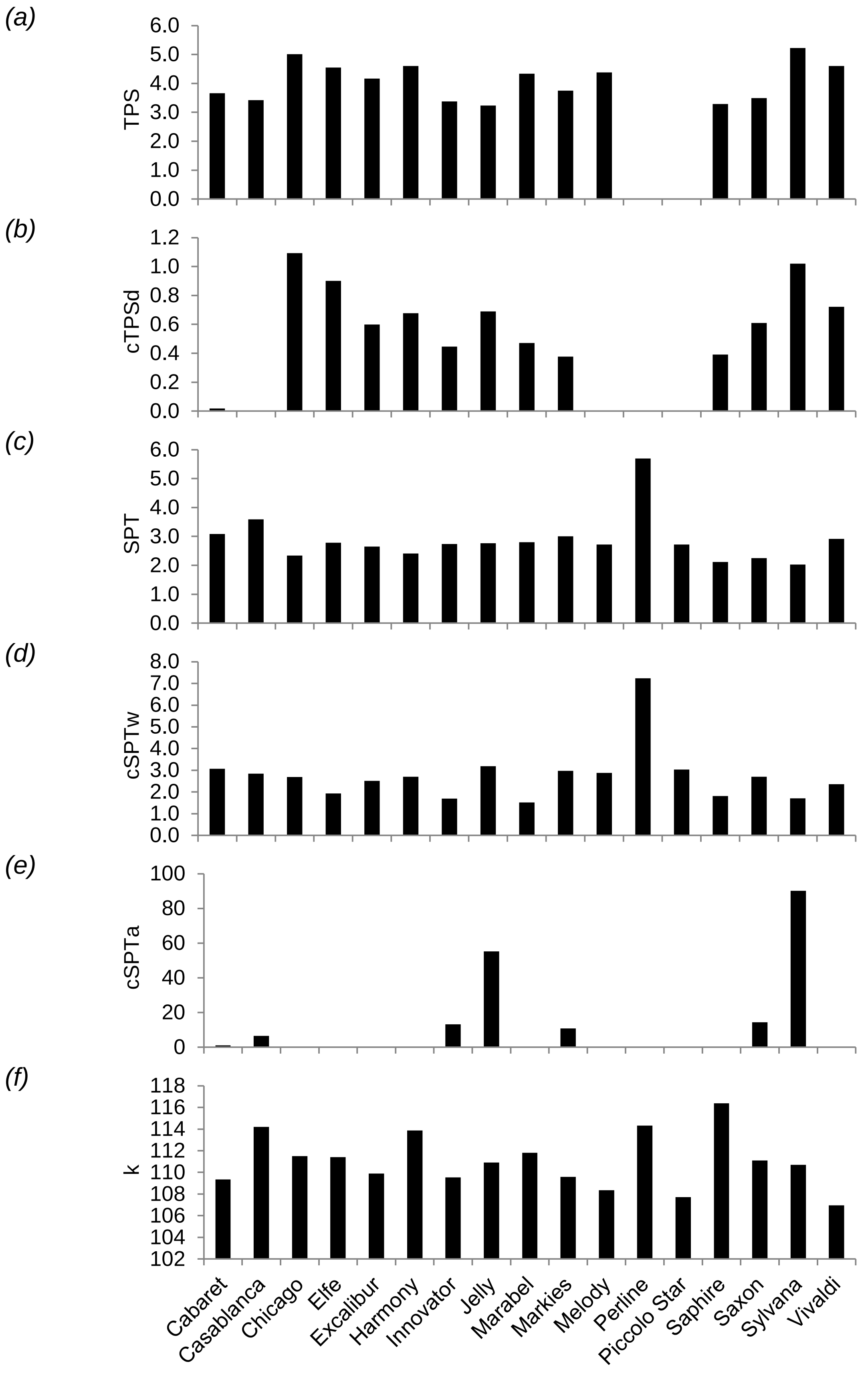
4. RESULTS

For most varieties there was relatively little data supplied from collaborators experiments or obtained from field crop sampling so that data were mainly from the experiments in Cambridge (Table 3). For six varieties (Casablanca, Innovator, Jelly, Markies, Perline and Saphire) a more extensive set of data was collected with at least 25 values obtained for the key variety characters. For other varieties with the exception of Excalibur which was only included in the Cambridge experiments in 2011 and 2012, at least 11 values were obtained for the key variety characters and in most cases data from the Cambridge experiments was largely consistent between years. Estimates of the variety characters described in Table 2 for the varieties included in this project are shown in Figure 2.

Table 3. Summary of number of collated datasets

Variety	Total	From NIAB-CUF expts	For TPS,TPSd, logS, logC	For SPT, cSPTw	For cSPTa	For k
Cabaret	20	14	20	20	12	15
Casablanca	39	18	39	38	30	25
Chicago	12	11	12	12	4	12
Elfe	17	12	15	15		13
Excalibur	5	5	5	5		5
Harmony	13	9	13	13		13
Innovator	39	13	39	39	37	28
Jelly	150	14	127	66	49	78
Marabel	23	13	20	17		17
Markies	49	11	49	46	44	27
Melody	13	8	13	12		13
Perline	69	13	69	46	11	69
Piccolo Star	21	12	12	21		12
Saphire	33	11	31	33		14
Saxon	11	10	11	11	7	11
Sylvana	46	2	46	21	21	40
Vivaldi	20	10	16	16		12

Figure 2. Estimated parameters for variety characters influencing seed rate requirements (see Table 2).



There were distinct relationships between the number of tubers and stems for each variety with relatively large numbers of tubers per stem at 100 000 stems/ha (TPS) in Sylvana and Chicago and relatively few in Jelly and Saphire (Figure 2*a*). Although Chicago also had a relatively high rate of change in tubers per stem around 100 000 stems per ha (cTPSd Figure 2*b*) it still produced high tuber populations at high stem densities (Figure 3*a*). For Jelly a low value for TPS and intermediate cTPSd (Figure 2) was associated with production of relatively few tubers at high stem populations (Figure 3*d*). With intermediate values for both TPS and cTPSd, the overall relationships between numbers of tubers and numbers of stems for varieties like Markies and Marabel were also intermediate (Figure 2, Figure 3*b*-*c*). The value of TPS at a stem density of 100 000/ha in Perline and Piccolo Star is not a useful character as crops of these varieties have much higher stem populations and both these varieties can produce very high tuber populations (Figure 4). Data from the CUF experiments generally tended to lie closer to the mean relationship between numbers of tubers and stems than data from other sources however whilst these data showed greater scatter, there was generally no evidence of systematic differences between the two data sources (e.g. Figure 3*b*-*d*).

The number of stems per seed tuber (SPT) varied considerably between varieties with Perline producing a particularly large number of stems whilst few stems were produced by Sylvana, Saphire and Saxon (Figure 2*c*). Change in number of stems with change in seed tuber weight (cSPTw) was also very high in Perline (Figure 2*d*) so that large seed produced more than 10 stems per tuber (Figure 5*a*). In contrast with low values in Saphire for both SPT and cSPTw (Figure 2*c*) few stems were produced for all seed sizes (Figure 5*b*). Varieties like Casablanca with a relatively high SPT and low cSPTw and Chicago with relatively low SPT and high cSPTw had less extreme relationships between numbers of stems per tuber and seed weight (Figure 5*c*-*d*).

Figure 3. **Relationship between number of tubers and number of stems in *(a)* Chicago, *(b)* Markies, *(c)* Marabel and *(d)* Jelly. Data from the experiments at Cambridge, 2011, ●; 2012, ■, 2013, ▲. Data from field crops and collaborators' experiments, 2011, ○; 2012, □; 2013 △.**

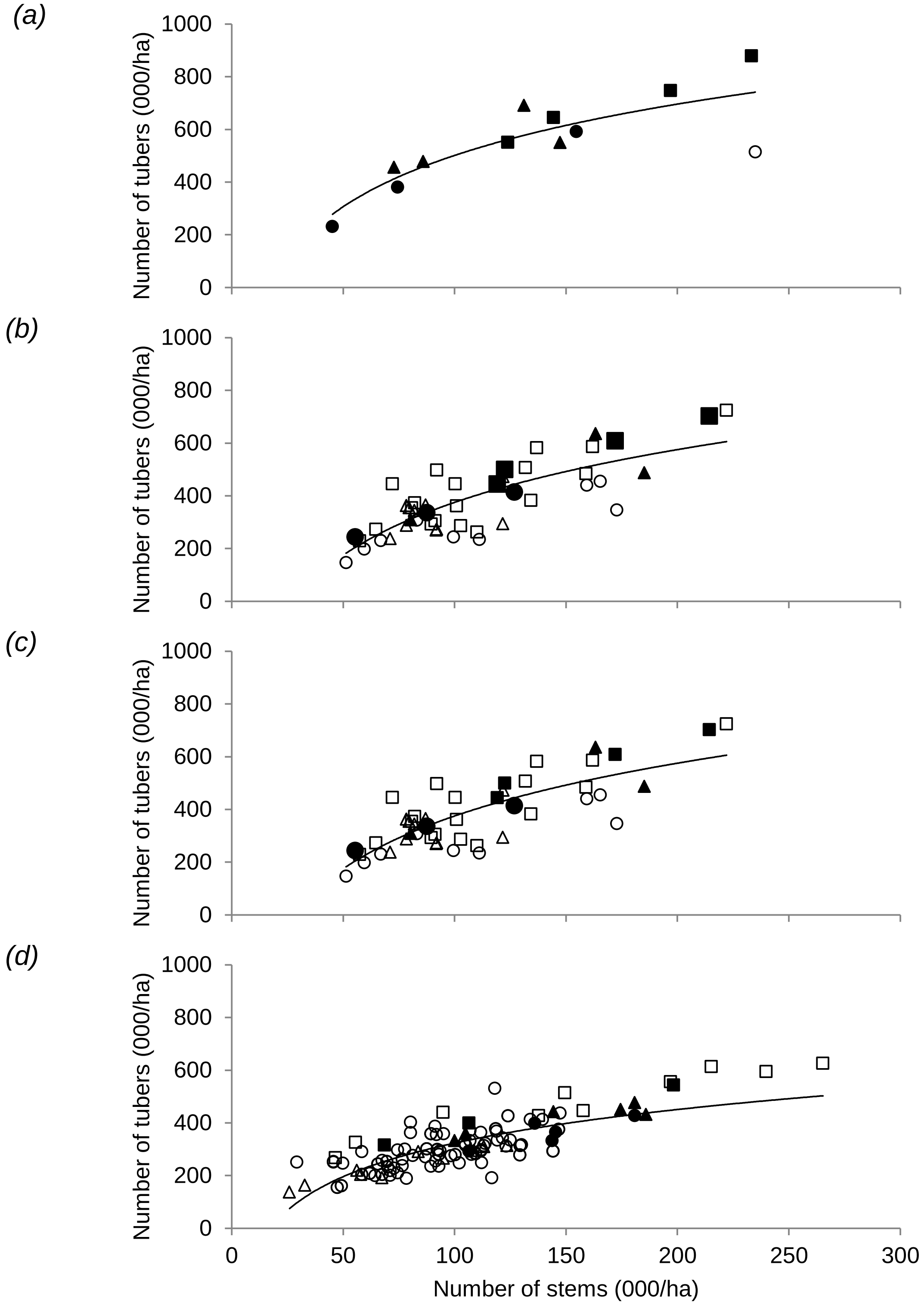


Figure 4. Relationship between number of tubers and number of stems in *(a)* Piccolo Star and *(b)* Perline. Data from the experiments at Cambridge, 2011, ●; 2012, ■, 2013, ▲. Data from field crops and collaborators' experiments, 2011, ○; 2012, □; 2013 △.

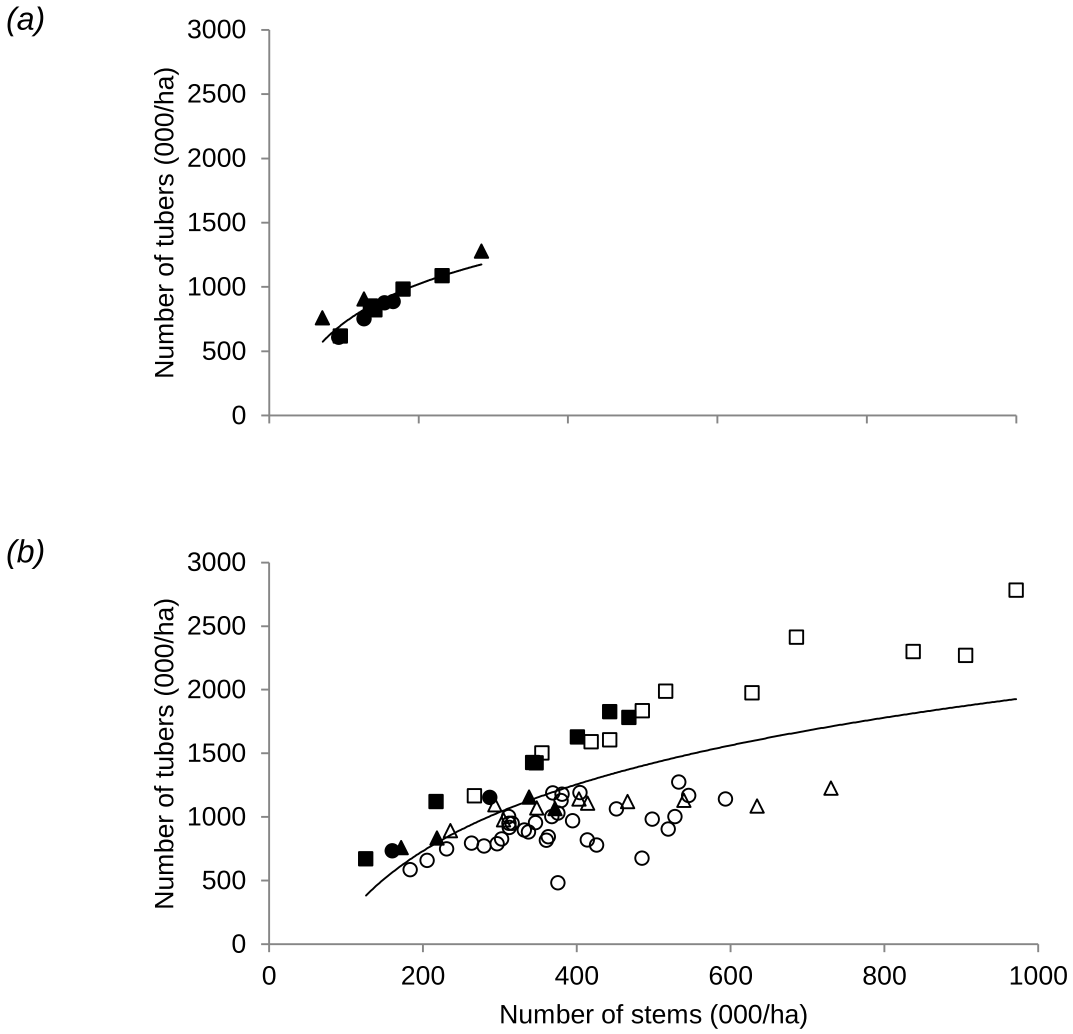
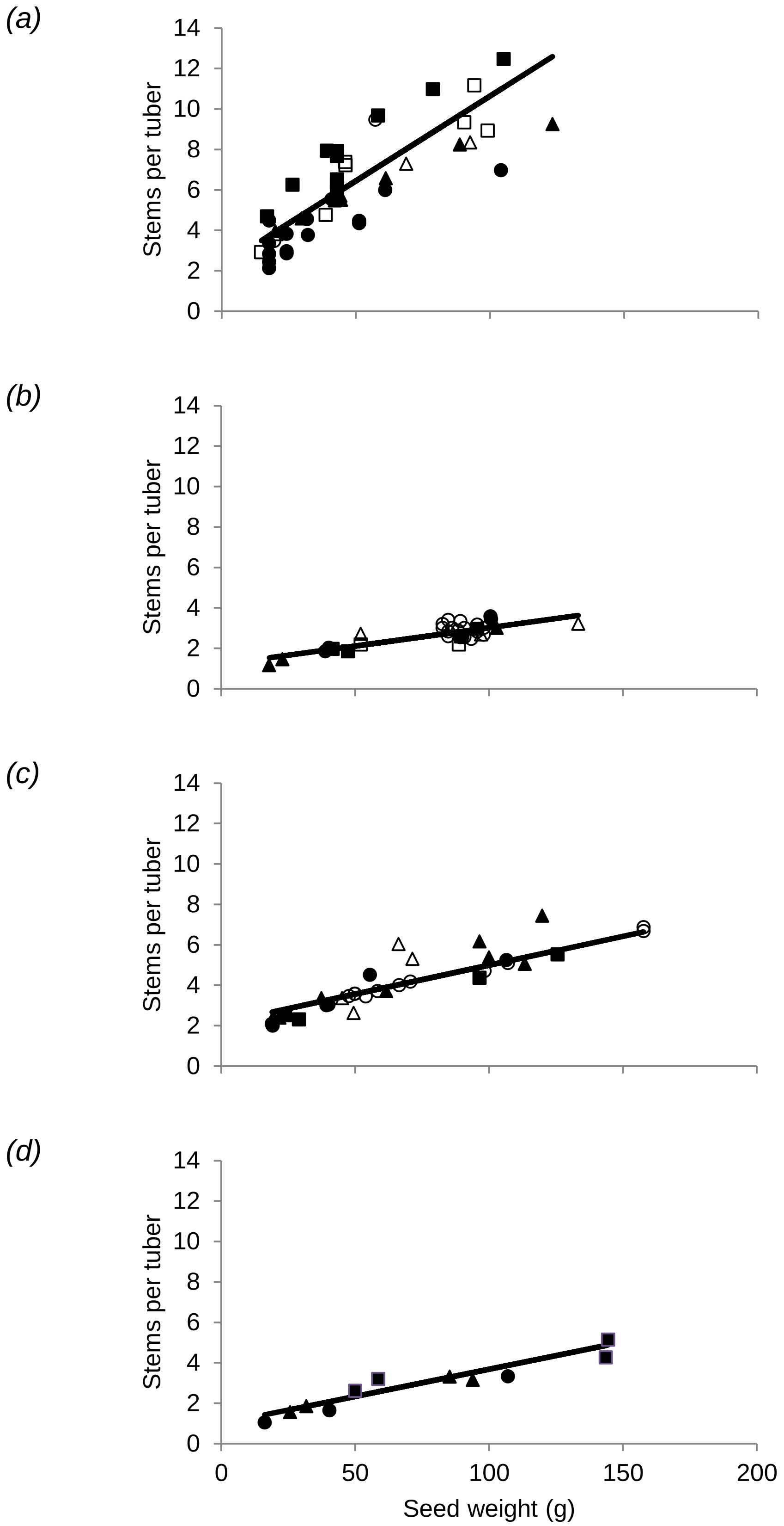
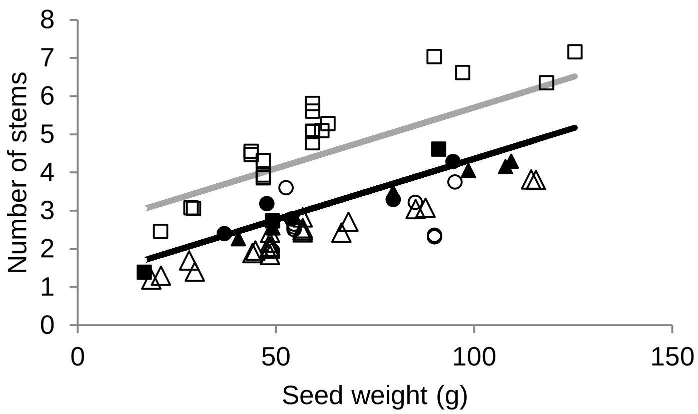


Figure 5. Relationship between number of stems per tuber and seed tuber weight in *(a)* Perline, *(b)* Saphire, *(c)* Casablanca and *(d)* Chicago. Data from the experiments at Cambridge, 2011, ●; 2012, ■, 2013, ▲. Data from field crops and collaborators' experiments, 2011, ○; 2012, □; 2013 △. Fitted lines are linear regressions not accounting for seed age.



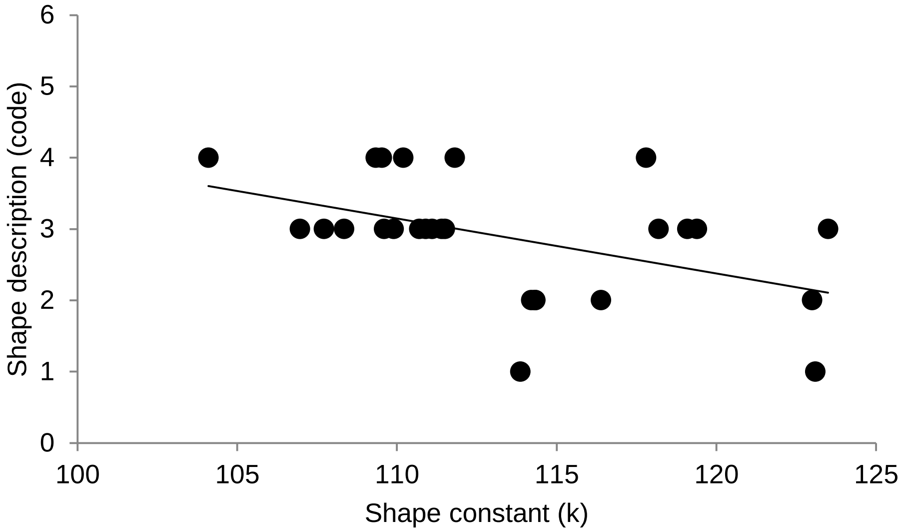
No seed age information was available for eight of the varieties and for two others seed age data were only available for a small proportion of the stocks but for seven varieties some estimate of the effect of seed age on the number of stems produced per seed tuber could be made. Estimates of the effect of seed age were very small for Cabaret and quite small for Casablanca but in all cases increase in seed age was associated with an increase in the number of stems produced (Figure 2*e*). The largest effects of seed age were for Jelly and Sylvana in which increase in seed age of a month was estimated to increase the number of stems by *c*. 55 and 90 %, respectively however these are based on a limited range in seed production dates particular in the case of Sylvana for which the effect of seed age is mainly derived from differences between stem production of seed stocks in 2011 and 2012 and more data are required to provide a reliable estimate of the effect of age in these varieties. Relationships between the number of stems and seed weight for contrasting seed ages in Jelly are illustrated in Figure 6. Smaller increases in stem number from increase in seed age (*c*. 10-14 % per month) were estimated for Markies, Innovator and Saxon.

Figure 6. Relationship between number of stems per tuber and seed tuber weight in Jelly. Data from the experiments at CUF, 2011, ●; 2012, ■, 2013, ▲. Data from field crops and collaborators' experiments, 2011, ○; 2012, □; 2013 △. Fitted lines are linear regressions for standard age seed of 318 days, black line and older seed of 348 days, grey line.



Estimates of the tuber shape constant (k) varied from 107 in Vivaldi to 116 in Saphire (Figure 2). Whilst relatively low estimates of k for Innovator and Markies (Figure 2) are consistent with their long shape and suitability for chipping, there was apparently little correspondence between the estimates of k and descriptions of shape in variety databases and very little variation in tuber shape was accounted for by linear regression with shape code (Figure 7). For example both Vivaldi and Chicago are described as oval whilst having quite different k values (Figure 2*f*).

Figure 7. Relationship between tuber shape description code and tuber shape constant for 27 varieties. Tuber shape codes 1-6 represent round, oval to round, oval, oval to long, long to oval and very long respectively. Fitted line y=-0.077x+11.613; r^2 = 0.220.



4.1. Seed rates

Seed rate tables (see Appendices) were collated for standard age seed and based on a mean tuber size of 60 mm for table and processing varieties and 37.5 – 43 mm for salad varieties. Tables for different specifications can be readily calculated but the above specifications should provide for useful initial recommendations.

For seven of the table and processing varieties (Cabaret, Casablanca, Innovator, Jelly, Markies, Saphire and Saxon), tables appropriate for yields from 50 – 70 t/ha were collated but for four varieties (Elfe, Excalibur, Harmony and Marabel), to achieve a mean tuber size of 60 mm at a relatively low yield of 50 t/ha would require such low stem populations (< 75 000 /ha) that total yield could be compromised and tables were only collated for yields of 60 – 70 t/ha. Similarly for three varieties (Chicago, Sylvana and Vivaldi), seed rates were only collated for a mean tuber size of 60 mm and yields of 70 t/ha because stem populations to achieve a 60 mm mean tuber size at lower yields could compromise total yield. Where lower yields are expected, these seed rates should usually still be appropriate although the mean tuber size achieved would be expected to be below 60 mm resulting in a smaller proportion of yield in the larger size fractions.

Seed rates for the same crop specification were relatively high for Saphire, Jelly, Saxon and Innovator and in the case of Innovator, a marked increase in seed rate required with larger seed was notable (see Appendices). Relatively low seed rates were associated with Vivaldi, Chicago and Melody. Marabel and Sylvana also had low seed rates for small seed but the increase in seed rates with increase in seed size was quite marked (see Appendices).

The large number of stems produced by Perline and large numbers of tubers per stem produced by Piccolo Star result in relatively low seed rates required for producing salad crops however the large number of stems in Perline allow establishment of crops with lower seed rates than Piccolo Star without compromising total yield.

5. Discussion and Conclusions

Data collected over the three years were very consistent for many varieties particularly from the experiments conducted at Cambridge. This consistency in different years despite quite contrasting growing conditions indicates the parameters estimated from the data and seed rate recommendations derived from them should be quite generally applicable.

For some seed stocks of particular varieties, the relationship between number of stems per plant and seed weight deviated considerably from the average responses and these deviations may have resulted from differences in seed age, seed health and seed storage but in most cases the relative importance of these factors could not be determined. Nevertheless, the range in parameters derived from the average response for the different varieties was considerable and is an important contributor to differences in derived seed rate recommendations for seed of unspecified origin of different varieties.

For all varieties there were distinct relationships between number of tubers and stems but these were generally similar over the three years for data from the Cambridge experiments and whilst data from collaborator's experiments and field crops were more variable, there was not generally any systematic difference between the different datasets with both falling either side of the average response. This indicates that whilst the number of stems per tuber can be increased or decreased in individual circumstances, related to particular combinations of factors such as soil type and planting date, data from the Cambridge experiments were fairly typical of the average response. Until the effects of environmental factors on the relationship between number of tubers and stems can be predictively quantified to provide more crop-specific recommendations, the relationships derived from the collected datasets should provide an unbiased prediction of tuber populations in relation to stem populations suitable for deriving seed rate recommendations.

Published tuber shape descriptions were not closely related to the tuber shape constant calculated from graded yield data so only a crude estimate of the tuber shape constant could be made without fitting a normal distribution which adds to the complexity of the system. The effect of tuber shape on calculated seed rates is however sufficiently large to be of considerable importance. For example, if the calculated tuber shape constant for Vivaldi (107) were to be substituted for a value of 111.8 calculated for an oval tuber shape from the (poor) relationship between the shape code and tuber constant, the stem population calculated for a 70 t/ha crop with mean tuber size of 60 mm would increase by *c*. 20 % leading to a similar increase in seed rates. It is likely organisations wishing to develop seed rates for new varieties will need assistance with analysis of graded data to establish values for tuber shape to determine seed rates accurately rather than relying on estimates derived from published tuber shape descriptors.

Although the effects of seed age on the number of stems produced by seed could only be examined for a minority of the varieties and even where data were available the range in seed age was often quite small, the analyses showed that increase in seed age was associated with increases in stem production in all varieties for which data were available. The range in estimated response between varieties was considerable and the very large response for two varieties (Sylvana and Jelly) is sufficient to markedly affect seed rate recommendations however for all the varieties included in this work more data is needed to provide reliable recommendations based on differences in seed age.

This work has demonstrated that a relatively simple system can be applied to derive seed rate recommendations for new varieties. Derivation of the parameters has however relied heavily on experiments at Cambridge and in some cases elsewhere conducted by collaborators rather than from data collected by crop sampling. Whilst the system can be largely operated using spreadsheet-based calculations, this study has indicated that data from simple but targeted experiments over at least two seasons will be required during the initial introduction of varieties to make provisional recommendations. Data from subsequent crop sampling and experiments in later seasons can be used to complement these datasets to give more reliable recommendations but the provenance of all data needs to be carefully evaluated. The information necessary for deriving effects of seed age is not currently routinely available and this, together with the added complexity of computing the effects of seed age, limits how readily this can be included in recommendations. For at least some varieties, the magnitude of effects of seed age can markedly influence efficient use of seed and could affect adoption of the varieties where inappropriate seed rates are used. Better systems for documenting seed and ware crop production in future should help in making the necessary information more widely available.

6. References

British Potato Variety Database http://www.varieties.potato.org.uk

European Cultivated Potato Database http://*www.europotato.org*

FIRMAN, D. M., ALLEN, E.J. & SHEARMAN, V. J. (2006). New seed rate recommendations. British Potato Council Report.

FIRMAN, D. M. & DANIELS, S.J. (2010) Factors affecting tuber numbers per stem leading to improved seed rate recommendations (Project Ref: 296) Final Report.

TRAVIS, K. Z. (1987). Use of a simple model to study factors affecting the size distribution of tubers in potato crops. Journal of Agricultural Science, Cambridge 109, 563-571.

7. APPENDICES

7.1. Values of parameters derived from collated data for calculation of seed rates.

Variety	k	TPS	SPT	cSPTw	cSPTa	TSc	TSs
Cabaret	109.3	3.66	3.09	3.07	1.1	-1217	344
Casablanca	114.2	3.42	3.59	2.85	6.5	-1190	333
Chicago	111.5	5.01	2.34	2.69		-793	281
Elfe	111.4	4.55	2.79	1.93		-796	272
Excalibur	109.9	4.17	2.65	2.51		-913	289
Harmony	113.9	4.60	2.41	2.71		-996	316
Innovator	109.5	3.37	2.74	1.70	13.3	-771	241
Jelly	110.9	3.23	2.76	3.19	55.3	-524	184
Marabel	111.8	4.34	2.80	1.52		-1097	335
Markies	109.6	3.75	3.00	2.98	10.8	-955	289
Melody	108.4	4.38	2.72	2.88		-2095	550
Perline	114.3		5.69	7.24		-3490	787
Piccolo Star	107.7		2.72	3.03		-1288	436
Saphire	116.4	3.29	2.11	1.82		-788	243
Saxon	111.1	3.49	2.25	2.70	14.4	-678	223
Sylvana	110.7	5.22	2.03	1.71	90.2	-923	314
Vivaldi	107.0	4.60	2.92	2.36		-960	308

7.2. Cabaret seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	37.9	0.79	45.2	0.94	53.9	1.12
2000	35.8	0.90	42.7	1.07	51.0	1.27
1600	33.1	1.03	39.5	1.23	47.1	1.47
1200	29.4	1.22	35.0	1.46	41.8	1.74
1000	26.9	1.35	32.1	1.61	38.3	1.92
900	25.5	1.42	30.4	1.69	36.3	2.02
800	24.0	1.50	28.6	1.79	34.1	2.13
700	22.2	1.59	26.5	1.89	31.6	2.26
600	20.2	1.69	24.1	2.01	28.8	2.40
500	18.0	1.80	21.5	2.15	25.6	2.56
400	15.4	1.93	18.4	2.30	21.9	2.74

7.3. Casablanca seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	36.5	0.76	44.9	0.94	55.3	1.15
2000	35.0	0.88	43.1	1.08	53.0	1.32
1600	33.0	1.03	40.6	1.27	49.9	1.56
1200	30.1	1.25	37.0	1.54	45.5	1.90
1000	28.1	1.40	34.5	1.73	42.5	2.12
900	26.9	1.49	33.1	1.84	40.7	2.26
800	25.5	1.60	31.4	1.96	38.6	2.42
700	24.0	1.71	29.5	2.11	36.3	2.59
600	22.2	1.85	27.3	2.28	33.6	2.80
500	20.1	2.01	24.7	2.47	30.4	3.04
400	17.6	2.20	21.6	2.71	26.6	3.33

7.4. Chicago seed rate table (standard age seed)

Yield (t/ha)	70	
Mean tuber size (mm)	60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)
2400	53.4	1.11
2000	49.8	1.25
1600	45.3	1.42
1200	39.3	1.64
1000	35.5	1.78
900	33.4	1.86
800	31.1	1.94
700	28.5	2.04
600	25.7	2.14
500	22.6	2.26
400	19.1	2.38

7.5. Elfe seed rate table (standard age seed)

Yield (t/ha)	60		70	
Mean tuber size (mm)	60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	34.5	0.72	43.7	0.91
2000	33.3	0.83	42.2	1.05
1600	31.7	0.99	40.1	1.25
1200	29.3	1.22	37.0	1.54
1000	27.6	1.38	34.9	1.74
900	26.6	1.48	33.6	1.87
800	25.4	1.59	32.1	2.01
700	24.0	1.72	30.4	2.17
600	22.4	1.87	28.4	2.36
500	20.5	2.05	25.9	2.59
400	18.2	2.27	23.0	2.87

7.6. Excalibur seed rate table (standard age seed)

Yield (t/ha)	60		70	
Mean tuber size (mm)	60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	44.2	0.92	54.7	1.14
2000	41.9	1.05	51.8	1.30
1600	38.9	1.21	48.1	1.50
1200	34.7	1.45	42.9	1.79
1000	32.0	1.60	39.6	1.98
900	30.4	1.69	37.6	2.09
800	28.6	1.79	35.4	2.21
700	26.6	1.90	32.9	2.35
600	24.3	2.03	30.1	2.51
500	21.7	2.17	26.8	2.68
400	18.7	2.34	23.1	2.89

7.7. Harmony seed rate table (standard age seed)

Yield (t/ha)	60		70	
Mean tuber size (mm)	60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	52.7	1.10	65.5	1.36
2000	49.3	1.23	61.2	1.53
1600	44.9	1.40	55.7	1.74
1200	39.1	1.63	48.5	2.02
1000	35.4	1.77	44.0	2.20
900	33.4	1.85	41.4	2.30
800	31.1	1.94	38.6	2.41
700	28.6	2.04	35.5	2.53
600	25.8	2.15	32.0	2.67
500	22.7	2.27	28.2	2.82
400	19.2	2.40	23.9	2.98

7.8. Innovator seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	38.8	0.81	49.9	1.04	64.3	1.34
2000	37.6	0.94	48.4	1.21	62.3	1.56
1600	35.9	1.12	46.3	1.45	59.6	1.86
1200	33.5	1.40	43.1	1.80	55.5	2.31
1000	31.8	1.59	40.9	2.04	52.6	2.63
900	30.7	1.71	39.5	2.20	50.9	2.83
800	29.5	1.84	37.9	2.37	48.8	3.05
700	28.0	2.00	36.1	2.58	46.5	3.32
600	26.3	2.19	33.9	2.82	43.6	3.63
500	24.2	2.42	31.2	3.12	40.2	4.02
400	21.7	2.71	27.9	3.49	35.9	4.49

7.9. Jelly seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	52.4	1.09	73.9	1.54	104.2	2.17
2000	48.9	1.22	68.9	1.72	97.1	2.43
1600	44.4	1.39	62.6	1.95	88.2	2.76
1200	38.5	1.60	54.2	2.26	76.4	3.18
1000	34.8	1.74	49.0	2.45	69.1	3.45
900	32.7	1.81	46.0	2.56	64.9	3.61
800	30.4	1.90	42.8	2.68	60.3	3.77
700	27.9	1.99	39.3	2.81	55.4	3.95
600	25.1	2.09	35.4	2.95	49.9	4.15
500	22.0	2.20	31.1	3.11	43.8	4.38
400	18.6	2.33	26.2	3.28	37.0	4.62

7.10. Marabel seed rate table (standard age seed)

Yield (t/ha)	60		70	
Mean tuber size (mm)	60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	35.9	0.75	43.5	0.91
2000	34.9	0.87	42.4	1.06
1600	33.6	1.05	40.8	1.27
1200	31.6	1.32	38.4	1.60
1000	30.2	1.51	36.6	1.83
900	29.3	1.63	35.6	1.98
800	28.3	1.77	34.3	2.14
700	27.1	1.93	32.8	2.34
600	25.6	2.13	31.0	2.59
500	23.8	2.38	28.8	2.88
400	21.5	2.68	26.0	3.26

7.11. Markies seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	36.8	0.77	45.4	0.95	56.1	1.17
2000	34.8	0.87	42.9	1.07	53.0	1.32
1600	32.1	1.00	39.6	1.24	49.0	1.53
1200	28.5	1.19	35.2	1.47	43.4	1.81
1000	26.1	1.31	32.3	1.61	39.8	1.99
900	24.8	1.38	30.6	1.70	37.8	2.10
800	23.2	1.45	28.7	1.79	35.4	2.21
700	21.5	1.54	26.6	1.90	32.8	2.35
600	19.6	1.64	24.2	2.02	29.9	2.49
500	17.5	1.75	21.6	2.16	26.6	2.66
400	15.0	1.87	18.5	2.31	22.8	2.85

7.12. Melody seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	41.0	0.85	45.6	0.95	50.8	1.06
2000	38.5	0.96	42.9	1.07	47.7	1.19
1600	35.4	1.10	39.4	1.23	43.8	1.37
1200	31.1	1.29	34.6	1.44	38.5	1.60
1000	28.3	1.42	31.5	1.58	35.1	1.76
900	26.8	1.49	29.8	1.65	33.2	1.84
800	25.0	1.56	27.9	1.74	31.0	1.94
700	23.1	1.65	25.7	1.84	28.6	2.04
600	20.9	1.75	23.3	1.94	26.0	2.16
500	18.5	1.85	20.6	2.06	23.0	2.30
400	15.8	1.97	17.6	2.20	19.6	2.45

7.13. Perline seed rate table (standard age seed)

Yield (t/ha)	35		35		40	
Mean tuber size (mm)	43		37.5		37.5	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	54.5	1.13	83.3	1.73	99.7	2.08
2000	50.2	1.26	76.8	1.92	91.9	2.30
1600	45.0	1.41	68.8	2.15	82.3	2.57
1200	38.3	1.60	58.6	2.44	70.1	2.92
1000	34.3	1.71	52.4	2.62	62.7	3.13
900	32.0	1.78	48.9	2.72	58.5	3.25
800	29.6	1.85	45.2	2.82	54.1	3.38
700	26.9	1.92	41.1	2.94	49.3	3.52
600	24.1	2.00	36.8	3.06	44.0	3.67
500	20.9	2.09	32.0	3.20	38.3	3.83
400	17.5	2.19	26.8	3.35	32.1	4.01

7.14. Piccolo Star seed rate table (standard age seed)

Yield (t/ha)	30		35		40	
Mean tuber size (mm)	37.5		37.5		37.5	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	53.3	1.11	69.9	1.46	91.7	1.91
2000	49.8	1.25	65.4	1.63	85.8	2.15
1600	45.5	1.42	59.6	1.86	78.3	2.45
1200	39.6	1.65	52.0	2.17	68.2	2.84
1000	36.0	1.80	47.2	2.36	61.9	3.10
900	33.9	1.88	44.4	2.47	58.3	3.24
800	31.6	1.97	41.4	2.59	54.3	3.40
700	29.0	2.07	38.1	2.72	50.0	3.57
600	26.2	2.19	34.4	2.87	45.1	3.76
500	23.1	2.31	30.3	3.03	39.8	3.98
400	19.6	2.45	25.7	3.21	33.7	4.22

7.15. Saphire seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	71.7	1.49	96.6	2.01	130.0	2.71
2000	68.4	1.71	92.1	2.30	124.0	3.10
1600	64.0	2.00	86.2	2.69	116.1	3.63
1200	57.8	2.41	77.9	3.24	104.8	4.37
1000	53.7	2.68	72.3	3.61	97.3	4.86
900	51.2	2.85	69.0	3.83	92.8	5.16
800	48.5	3.03	65.2	4.08	87.8	5.49
700	45.3	3.24	61.0	4.36	82.1	5.87
600	41.7	3.47	56.1	4.68	75.6	6.30
500	37.5	3.75	50.5	5.05	68.0	6.80
400	32.6	4.07	43.9	5.49	59.1	7.38

7.16. Saxon seed rate table (standard age seed)

Yield (t/ha)	50		60		70	
Mean tuber size (mm)	60		60		60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)	Plant population (000/ha)	Seed rate (t/ha)
2400	59.3	1.24	78.8	1.64	104.8	2.18
2000	55.1	1.38	73.2	1.83	97.3	2.43
1600	49.7	1.55	66.1	2.07	87.9	2.75
1200	42.8	1.78	56.9	2.37	75.7	3.15
1000	38.6	1.93	51.2	2.56	68.1	3.41
900	36.1	2.01	48.0	2.67	63.9	3.55
800	33.5	2.10	44.6	2.79	59.2	3.70
700	30.7	2.19	40.8	2.91	54.2	3.87
600	27.5	2.29	36.6	3.05	48.7	4.05
500	24.1	2.41	32.0	3.20	42.6	4.26
400	20.3	2.54	27.0	3.37	35.9	4.48

7.17. Sylvana seed rate table (standard age seed)

Yield (t/ha)	70	
Mean tuber size (mm)	60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)
2400	50.2	1.05
2000	48.0	1.20
1600	45.0	1.41
1200	40.7	1.70
1000	37.9	1.89
900	36.2	2.01
800	34.3	2.14
700	32.1	2.29
600	29.6	2.46
500	26.6	2.66
400	23.2	2.90

7.18. Vivaldi seed rate table (standard age seed)

Yield (t/ha)	70	
Mean tuber size (mm)	60	
Tuber count (per 50 kg)	Plant population (000/ha)	Seed rate (t/ha)
2400	36.5	0.76
2000	35.0	0.87
1600	32.9	1.03
1200	29.9	1.25
1000	27.9	1.40
900	26.7	1.48
800	25.3	1.58
700	23.8	1.70
600	22.0	1.83
500	19.9	1.99
400	17.4	2.17

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