TOWARDS A PREDICTION OF YIELD, BULB SIZE DISTRIBUTION AND TIME TO MATURITY IN ONION CROPS

[1]J.E. Lancaster, [2]C.M. Triggs and [3]L. Barrett
[1]Applied Biochemistry Division, DSIR Lincoln
[2]Applied Mathematics Division, DSIR Auckland
[3]Hort. Advisory Officer, MAF Pukekohe

ABSTRACT

Factors affecting the development of onions and their mode of growth have been described from a variety of points of view. To determine the most important factors affecting the development of the local cultivars Pukekohe Long Keeper and Early Long Keeper, onions were monitored throughout the growing season at eighteen sites in the Pukekohe district. We discuss the construction of an empirical growth model to predict yield, distribution of bulb size and the time until the onset of bulbing and to maturity. Results from the first season indicate that the growth pattern of an onion is independent of its final size, and that early planting does not lead to early maturity. The differences between the two cultivars are explored.

Additional Key Words: growth model, Pukekohe Long Keeper, Early Long Keeper.

INTRODUCTION

The onion (*Allium cepa*) is a biennial plant, and the bulb is a vegetative overwintering stage in the life cycle of the plant. An onion plant is composed of leaves which arise alternately from a small flattened stem, or base plate, so that older leaves are on the outside and younger leaves on the inside of the stem. Each leaf is composed of a photosynthetic leaf blade and a non-photosynthetic, storage leaf base (scale). During the growth of the plant the leaf scales thicken and form the characteristic bulb.

It has long been known that the daylength and temperature play vital roles in the formation and final size of the bulb (Holdsworth and Heath, 1950). Steer (1980) showed the importance of night temperature in the induction of bulbing in phytotron-grown plants, and Lercari (1983) and Austin (1972) showed that far-red light was also necessary.

The interaction between the environment and the growth and average yield of onion crops has been studied extensively at Wellesborne, Britain (Dowker, *et al.* 1976, Brewster, *et al.* 1977; Brewster and Barnes 1981; Brewster 1982). In addition, many studies have looked at the effect of one variable on the yield of the crop e.g. irrigation (de Lis, *et al.* 1967; van Eeden and Myburgh, 1971; Chaudhry and Erinne, 1984), fertilizer application (Hassan and Ayoub, 1978), weed competition (Hewson and Roberts, 1973) and planting density (Rogers, 1977).

In modelling the response of a plant to its environment, a number of approaches have been adopted. Aggregate models, which relate mean yield of a crop to thermal time or to intercepted radiation have been used by Brewster *et al.* (1977), and by de Ruiter (1986). More lately attempts have been made to develop models which also describe the variability of a crop (Porter 1984, Fishman *et at* 1985). Sands and Regel (1983) developed an empirical model for predicting yield and graded yield in potatoes, in which variance of the crop was expressed as a function of the mean. Gandar *et al.* (1984), in a study of tillering and yield of wheat, related variance in growth rates of tillers to variance in initial sizes of tillers, the size order being maintained.

The aim of this work was to construct an empirical model which could be used by growers to predict yield, the size of bulb and the time to maturity. We have tried to keep in mind the needs of a grower and to use data which would be accessible to an individual grower. In this paper we have outlined the key characteristics of plant development which such a model would have to encompass.

MATERIALS AND METHODS

Selection of onion crops

Eighteen sites were selected in the Pukekohe district, the main commercial onion growing area of New Zealand, by the MAF Horticultural Advisory Officer; twelve sites were at Pukekohe and six at Tuakau. The cultivars Pukekohe Long Keeper (PLK) and Early Long Keeper (ELK) were chosen at eight and ten sites respectively.

Cultural Conditions

The location, cultivar, and the dates for planting, emergence and harvest are shown in Table 1.

Measurement of onions

Fifty onions were randomly selected at each site and labelled individually. The diameter of each bulb (mm), and the diameter of the bulb and neck of five selected bulbs was measured fortnightly from the beginning of September until the end of October. Measurements were then continued weekly until harvest maturity which was defined as the time when more than 50% of the tops had fallen over. At harvest the fifty onions at each site were weighed individually, and all onions in a 20 m length of a bed 1.5 m wide were weighed and graded into four classes (small <60 mm, medium 60-70 mm, large 70-90 mm and jumbo >90 mm). The percentage of the onions at each site which had bolted was estimated.

TABLE 1: Cultural conditions for all sites.

Site	Cultivar	Location[1]	Dates of Planting	Dates of Emergence	Bolting	Yield (tonne/ha)
1	ELK	P	28/5	1/7	0	43.2
2	ELK	P	29/5	25/6	23	56.2
3	ELK	P	29/5	25/6	16	57.9
4	ELK	P	30/5	17/6	19	47.3
5	ELK	T	31/5	24/6	3	62.1
6	ELK	T	31/5	24/6	7	67.6
7	ELK	P	1/6	1/7	0	38.8
8	ELK	P	28/6	6/7	2	71.2
9	ELK	T	29/6	25/7	0	35.9
10	ELK	T	29/6	25/7	0	43.5
11	PLK	P	28/6	15/7	0	36.0
12	PLK	P	11/7	10/8	0	67.5
13	PLK	P	11/7	20/8	0	43.5
14	PLK	P	17/7	25/8	0	42.9
15	PLK	P	23/7	25/8	0	50.6
16	PLK	P	5/8	1/9	0	39.0
17	PLK	T	5/8	1/9	0	58.2
18	PLK	T	5/8	1/9	0	41.3

[1]Location; P = Pukekohe, T = Tuakau.

Figure 1a

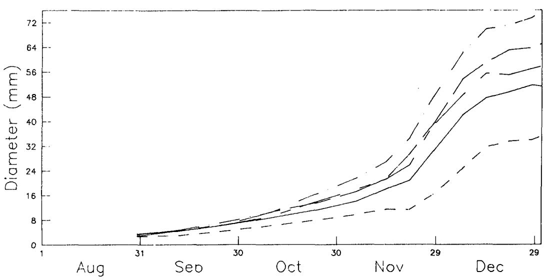


Figure 1b

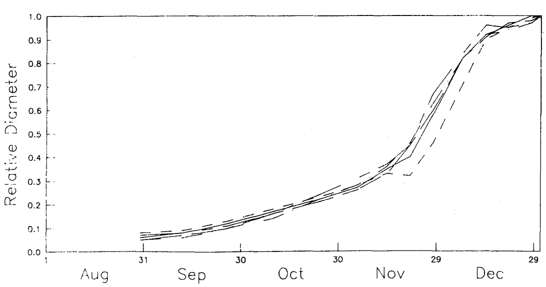


Figure 1: a) Changes in bulb diameter for 5 Early Long Keeper onions from site 4, from 1st measurement (29/8/85) to harvest (31/12/85).
b) Changes in bulb diameter relative to final diameter for 5 Early Long Keeper onions from site 4, from first measurement (29/8/85) to harvest (31/12/85).

RESULTS

Cultural Conditions

The crops we selected exemplified a range of cultural practises used in the commercial onion growing region (Table 1). The cultivar ELK was planted between late May and late June 1985; the time to 50% seedling emergence for each site was between 8 and 33 days. The cultivar PLK was planted between late June and early August, and 50% seedling emergence was between 17 and 40 days later. Between 0 and 23% of the ELK onions planted in May bolted, and yields varied between 35.9 and 71.2 tonnes/ha with a mean of 52.4 tonnes/ha. Yields of PLK varied between 36.0 and 67.5 tonnes/ha with a mean of 47.4 tonnes/ha. No bolting was observed.

Growth Patterns

Figure 1a illustrates the increase in diameter during the season for five ELK onions at site 4 which were of different sizes at final harvest. Each onion had a long period of slow growth during establishment, a short period of rapid linear bulb growth, and a slow "tailing off". To compare the growth of these onions, the size at any time was normalised by expressing it as a ratio of the final size. The five curves then coincided (Fig. 1b) which indicates that these onions grew the same way and began bulbing at the same time irrespective of their size. Similar analyses for each site confirmed these results.

TABLE 2: Time between phenological events for Early Long Keeper and Pukekohe Long Keeper onions at 18 sites.

Site	Cultivar	Number of days between Planting	Emergence	Bulbing	Harvest	Date of bulbing
1	ELK	34	140	42		18/11
2	ELK	27	146	40		20/11
3	ELK	27	146	40		20/11
4	ELK	18	154	42		18/11
5	ELK	24	149	40		20/11
6	ELK	24	145	44		16/11
7	ELK	30	140	42		18/11
8	ELK	8	135	42		18/11
9	ELK	26	118	40		20/11
10	ELK	26	118	40		20/11
11	PLK	30	119	63		13/11
12	PLK	17	121	87		7/12
13	PLK	40	110	62		8/12
14	PLK	39	105	62		8/12
15	PLK	33	95	72		28/11
16	PLK	27	103	57		13/12
17	PLK	27	113	47		23/12
18	PLK	27	108	52		18/12

Key Phenological Events

The time intervals (in calendar days) between planting, 50% emergence, bulbing and harvest are summarized for each crop in Table 2.

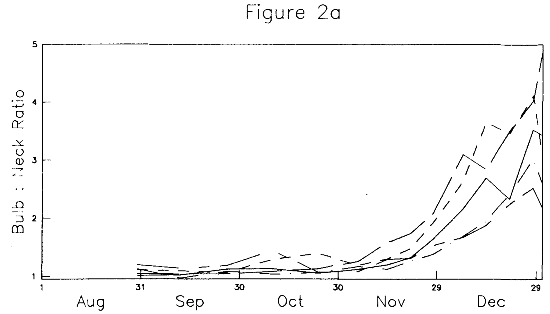
Seedling Emergence

Seedling emergence at each site occured over a 2-3 week period (L. Barrett pers. comm.), so that the time to

50% seedling emergence is recorded. There was a wide variation in the time to 50% emergence, with a maximum of 40 days for PLK site 13, and a minimum of 8 days for ELK site 8. There was no discernible trends in the length of time the seedlings took to germinate and emerge due to the site or variety.

Onset of bulbing

A change in the ratio of bulb diameter and neck diameters has long been used as a sensitive and reliable indicator of the commencement of bulbing (Mann, 1952). For much of the growth of the seedling the ratio is about 1.2 (Fig. 2a), and it then increases rapdily as the bulb expands. The statistical technique of cumulative sums or Cusums provides a sensitive way of detecting when the ratio consistently increases above 1.2 (Woodward and Goldsmith, 1964, British Standard, 1980). The target value is 1.2 and the accumulated differences between the actual ratio at any harvest and 1.2 are plotted. When the difference is consistently positive a point of inflection occurs, which can easily be detected. Using this procedure on the data in Fig. 2a, for ELK at site 10, revealed a sharp inflection in the graph at about November 20th (Fig 2b). Although the five onions were of different sizes, there was uniformity in the time of onset of bulbing. Cusums with a target of 1.2 were calculated for onions at each site. All the ELK onions bulbed at about the same time (18-20 Nov), despite the wide range of planting dates (Table 2). For the PLK onions there was a range of times of onset of bulbing. Plants at site 11, which were planted at the same time as the late planted ELK, bulbed in mid November. Onions planted in early July (Sites 12, 12, 14) bulbed in the first week of December, whilst those planted in early August (sites 16, 17, 18), bulbed in the second-third week in



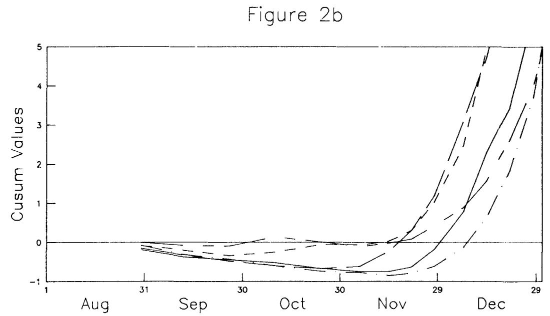


Figure 2: a) Ratio bulb to neck diameter during growth for 5 Early Long Keeper onions from site. 10.
b) Onset of bulbing as detected by Cusums target value of (1.2) of the bulb to neck diameter ratio for 5 Early Long Keeper onions from site 10.

TABLE 3: Total yield, distribution of bulb into 3 size classes by diameter (small < 60 mm, medium 60-70 mm, large 70-90 mm) and planting density for each site.

Site	Variety	Density (plants/m)	Percentage of plants in size class			Yield (tonne/ha)
			Small	Medium	Large	
1	ELK	8.7	32.1	34.8	33.2	43.2
2	ELK	14.0	47.5	42.7	9.8	56.2
3	ELK	14.9	63.8	31.2	5.0	57.9
4	ELK	12.5	75.2	24.5	0.3	47.3
5	ELK	9.3	22.9	46.1	31.1	62.1
6	ELK	12.4	22.3	65.3	13.2	67.6
7	ELK	7.9	40.3	33.4	26.2	38.8
8	ELK	—	35.6	61.7	2.7	71.2
9	ELK	7.7	46.7	32.2	17.0	35.9
10	ELK	12.5	63.4	33.8	2.8	43.5
11	PLK	10.8	58.6	36.5	4.9	36.0
12	PLK	14.9	42.7	46.6	10.7	67.5
13	PLK	10.5	39.0	48.7	12.3	43.5
14	PLK	10.2	54.6	44.8	17.7	42.9
15	PLK	14.9	39.0	49.5	11.5	50.6
16	PLK	13.0	74.5	24.5	1.0	39.0
17	PLK	10.0	17.7	41.6	40.6	58.2
18	PLK	11.0	32.1	46.4	21.5	41.3

December. It is of interest that at the onset of bulbing, the bulbs had diameters, which were 30-40% their final diameter. The size of the ELK bulbs in mid November for site 4 illustrates this point (Fig 1a).

Bulb Maturity

As an onion bulb approaches maturity, the remaining green leaves fall over at the neck (tops down), and there is a slowing of bulb growth before final leaf death. The change in the mean diameter of the onion bulb relative to final bulb size was plotted for each site throughout the season (Fig.3). The ELK onions matured in late December, about one month before the PLK onions. Furthermore, despite the wide ranges in planting date for each variety, there was a convergence in bulb maturity for ELK and ELK. The time between bulb and harvest was about 40 days for all ELK sites, but for PLK sites it ranged between 47 and 87 days (Table 2).

Distribution of Bulb Size

A general characteristic of onion crops is the range of the bulbs. Table 3 shows the mean yield, the proportions of plants in three size classes (<60 mm, 60-70 mm and 70-90 mm) and the density of planting for each site. Neither cultivar nor site appeared to affect the distribution of the size of the bulbs, and early planting did not produce larger bulbs. Plant populations ranged between 7 and 14 plants/metre but plant density alone could not account for the variation in the size distribution of bulbs. Sites 2, 3, 16 and sites 10, 13, 14 have similar final yields and similar densities of planting but different distributions of bulb size.

DISCUSSION

In this paper we have highlighted the characteristics of onion development which have to be taken into account in formulating a model for crop behaviour.

A unifying feature of the data is that all onions had the same growth pattern, irrespective of site, planting date, density and final size. Bulbing, a response of the plant to daylength and temperature, does not require the plant to be a certain size in order to receive the inductive stimulus. All ELK plants were induced to bulb at about the same time (November 16-20th) despite differences in size and differences in planting date of about a month. Plantings of PLK and ELK made at the same time also bulbed at mid November. However, late plantings of PLK bulbed up to 1 month later than plantings of ELK.

This raises the possibility that onion plants need to reach a stage of developmental readiness (not size per se) or have accumulated sufficient thermal time to be receptive to the bulbing stimulus. Brewster *et al.* (1977) suggested that plants needed to have initiated a certain number of leaves to be eligible to bulb when the daylength appropriate to that species was reached. It is feasible that the later planted PLK crops reach the required developmental readiness or amount of thermal time after the inductive photoperiod, so that there is no environmental delay to bulbing. All ELK crops would have reached developmental readiness before the inductive photoperiod.

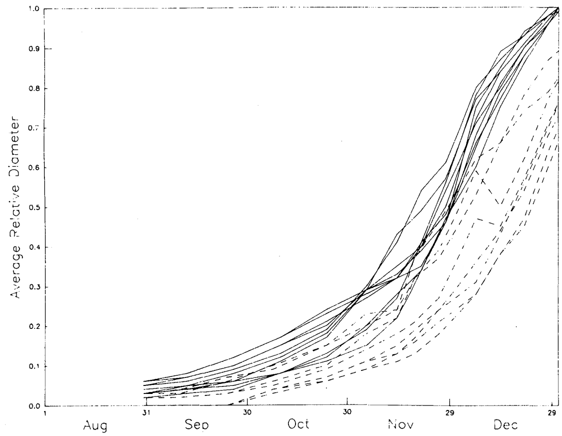


Figure 3: Changes in mean onion bulb diameter relative to final bulb diameter for all sites during growth. Early Long Keeper sites (——) and Pukekohe Long Keeper sites (---).

An unexpected finding of this survey was the convergence of maturity date and thus harvest for both varieties, and particularly for PLK. All ELK crops bulbed at the same time, so it was not too unexpected that they should mature at the same time. But PLK crops all finished growing at a similar time in late January, despite the fact that there was up to 1 month's difference in bulbing. The reason for this convergence of maturity remains to be elucidated.

The results from this survey raised questions about the nature of the differences between the ELK and PLK varieties. ELK and PLK crops planted at similar times bulbed at similar times, which suggests that both varieties respond to the same daylength signal. However, those same PLK crops matured later. Growth curves suggest that ELK may have a faster growth rate (Fig. 3). Furthermore the time from bulbing to harvest for ELK crops is about half that of PLK crops, despite the fact that temperatures in December were lower than those in January. Table 3 showed that yields of ELK crops were slightly higher than those of PLK crops, and this was not attributable to plant density. We suggest that in breeding for the ELK cultivar plant breeders have selected for a faster growing plant, rather than a plant with a shorter daylength response.

An intrinsic characteristic of onions, is the wide range of bulb sizes. This is used to advantage commercially as large sized bulbs gain a premium price. To be useful in the commercial sector, any model of onion growth must therefore be able to account for the size distribution of variance of bulbs.

Density of planting has long been known to affect the size of bulbs. Lower densities produce larger bulbs and higher densities produce smaller bulbs. However, the range of densities on these sites is rather narrow, and density alone cannot account for the size distributions in this survey. Also, plants are widely spaced for much of the time before bulbing, and competition for either above or below ground resources is unlikely to occur.

Differences in seedling emergence may also account for distributions of bulb size. PLK onion seeds may take up to 2 weeks to germinate, even when 100% viable and grown in a uniform environment on filter paper (J. Lancaster, unpublished data). Any size orders set up early in growth may be maintained to maturity, as has been reported to occur in tillers of wheat (Gandar *et al.* 1984). Once seedlings have emerged differences in growth rates may add to the spread of size classes. Brewster and Barnes (1981) reported different growth rates in onion seedlings which germinated synchronously. Onions are an open pollinated crop and as such it is feasible that genotype greatly influences variation in seedling emergence and seedling growth rates.

We have so far discussed the characteristics of the plant which need to be taken into account in developing an empirical model. Future work will aim to integrate this plant biology into agronomic performance.

ACKNOWLEDGEMENTS

We wish to thank Mr and Mrs M. and V. Monro, and Messrs B. Magon and N. Jollands for measuring the onions. We also wish to thank all the Pukekohe Growers who made their crops available to us and who co-operated by keeping management records.

REFERENCES

Austin, R.B. 1972. Bulb formation in onions as affected by photoperiod and spectral quality of light. *Journal of Horticultural Science 47:* 492-504.

Brewster, J.L. 1982. Growth, dry matter partitioning and radiation interception in an overwintered bulb onion *(Allium cepa)* crop. *Annals of Botany 49:* 609-617.

Brewster, J.L. and Barnes, A. 1981. A comparison of relative growth rates of different individual plants and different cultivars of onion of diverse geographic origin at two temperatures and two light intensities. *Journal of Applied Ecology 18:* 589-604.

Brewster, J.L., Salter P.J., and Darby R.J. 1977. Analysis of the growth and yield of overwintered onions. *Journal of Horticultural Science 52:* 335-346.

British Standard 5703: Part 1 (1980) Data analysis and quality control using CUSUM techniques. British Standards Institution, Hemel Hempstead.

Chaudhry, A.B. and Erinne, E.C. 1984. Determination of optimum irrigation frequency for onion in the Kainji Lake Region of Nigeria Savanna. *Garten bauwissenschaft 49:* 117-121.

de Lis, B.R., Ponce I., Cavagnaro, J.B. and Tizio R.M. 1967. Studies of water requirements of horticultural crops: II Influence of drought at different growth stages of onion. *Agronomy Journal 59:* 573-576.

de Ruiter, J.M. 1986. The effects of temperature and photoperiod on onion bulb growth and development. *Proceedings of the Agronomy Society of New Zealand* 16:

Dowker, B.D., Hardwick R.C., Fennell, J.F.M. and Andrews, D.J. 1976 Genotypic and environmental correlations between leaf growth and bulb size in onions. *Annals of Applied Biology 82:* 341-348.

Fishman, S., Talpaz, H., Winograd, R., Dinar, M., Arazi, Y., Roseman, Y., and Varshavski, S., (1985), A model for simulation of Potato Growth on the plant community level. *Agricultural Systems 18,* 115-128.

Gandar, P.W., Bertaud, D.S., Cleghorn, J.A., Withers, N.J. and Spriggs, T.W. 1984. Modelling tiller and yield formation in spring-sown Karamu wheat. *Proceedings of the Agronomy Society of New Zealand 14:* 83-87.

Hassan, M.S., and Ayoub A.T. 1978. Effects of N, P and K on yield of onion in the Sudan Gezira. *Experimental Agriculture 14:* 29-32.

Hewson, B.T. and Roberts, H.A. 1973. Some effects of weed competition on the growth of onions. *Journal of Horticultural Science 48:* 51-57.

Holdsworth, M. and Heath O.V.S., 1950. Studies on the physiology of the onion plant IV. The influence of day length and temperature on the flowering of the onion plant *Annals of Applied Biology 31:* 173-186.

Lercari, B., 1983 Action spectrum for the photoperiodic induction of bulb formation in *Allium cepa* L. *Photochemistry and Photobiology 38:* 219-222.

Mann, L.K. (1952). Anatomy of the garlic bulbs and factors affecting bulb development. *Hilgardia 21:* 195-251.

Porter, J.R., (1984), A model of canopy development in winter wheat. *Journal of Agricultural Science, Cambridge 102.* Camb., 102, 383-392.

Rogers, I.S., 1977. The influence of plant spacing on the frequency distribution of bulb weight and marketable yield of onions. *Journal of Horticultural Science 53:* 153-161.

Sands, P.J. and Regel, P.A. 1983. A model of the development and bulking of potatoes *(Solanum tuberosum* L.). V. A simple model for predicting graded yields. *Field Crops Research 6:* 25-40.

Steer, B.T. 1980. The role of night temperature in the bulbing of onion *(Allium cepa* L.) *Australian Journal of Agricultural Research 31:* 519-523.

Van Eeden, F.J., Myburgh J., 1971, Irrigation trials with onions *Agroplantae 3:* 57-62.

Woodward, R.H. and Goldsmith, P.L. (1964) Cumulative sum techniques, Imperial Chemical Industries (Oliver and Boyd) London.