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# THE PRACTICAL SIGNIFICANCE OF ACCUMULATED DAY-DEGREES AS A MEASURE OF PHYSIOLOGICAL AGE OF SEED POTATO TUBERS

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ABSTRACT

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Data are presented for the variety Pentland Javelin which demonstrate close relationships between emergence, leaf growth and tuber yields and number of accumulated day-degrees > 4° experienced by the seed tuber from the end of dormancy to the end of storage. Tuber yields increased with increasing number of day-degrees of seed tubers at early harvests and decreased with increasing number of day-degrees at final harvests. During the harvesting period negatively quadratic relationships between yields and number of day-degrees were found and the optimum number of day-degrees decreased with delay in harvesting. It is suggested that accumulated day-degrees > 4°C from end of dormancy to end of storage are a measure of physiological age of seed tubers and their significance is discussed in relation to the range of conditions in which potatoes are grown in Europe.

## INTRODUCTION

There is long-standing recognition of possible effects of seed-tuber production and storage on the growth and yield of ware potato crops (Hartman, 1934; Toosey, 1964a, b). These effects are physiological in origin and in recent years have been summarised under the term "physiological age". The importance of these effects has been recognised at recent conferences of the European Association for Potato Research (Bus and Schepers, 1978; Roztropowicz and Pietryka, 1981; Van Loon and Houwing, 1981) and considerable numbers of papers have been published which use the term. From these papers it is immediately evident that the term is still used loosely and frequently indiscriminately for various effects which may be connected with the seed tuber. The major reason for these difficulties is the lack of

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a measure of the term and the apparent reluctance of workers, particularly outside Great Britain, to seek a usable definition for their circumstances. The purpose of this paper is to present data which justify and illustrate the utility of the measure used in Great Britain and to discuss the relevance of this approach to other work on the subject of seed-tuber physiology.

## MATERIALS AND METHODS

In two experiments, once grown seed tubers of the variety Pentland Javelin were weighed, dipped in a solution of thiabendazole (1% active ingredient) and placed in single layers in trays in early October in an illuminated, controlled-temperature cabinet set at 12 ± 1°C. Details of both experiments are given in Table 1. When 90% of tubers had sprouts > 3 mm in length dormancy was considered to have ended and from this time seed tuber lots were moved at 2—3 week intervals to a similar cabinet set at 4 ± 0.5°C. The light intensity was similar in both cabinets, within the range 1.29 to 1.83 × $10^3$ lux. Thus, a range of treatments was produced, with a wide range of accumulated day-degrees > 4°C after end of dormancy but with only small differences in number of sprouts per tuber. Although only one temperature was used for sprouting, previous experiments (Wurr, 1979) had shown no differences in tuber yields between numbers of day-degrees achieved by different temperatures and durations. The validity of the choice of 4°C as the base temperature was discussed by O'Brien et al. (1983). At

TABLE 1

Details of the experiments

| | Experiment 1 | Experiment 2 |
|---|---|---|
| Year | 1978/79 | 1979/80 |
| Seed weight (g) | 55 ± 5 | 45 ± 5 |
| | 65 ± 5 | 60 ± 10 |
| | 77.5 ± 7.5 | 60 ± 10 |
| Plot size | 5 rows × 4.5 m | 5 rows × 4.95 m |
| Date of planting | 19 April | 24 March |
| Rate of fertilizer application (kg/ha) | N: 152 P: 65 K: 160 | N: 208 P: 89 K: 221 |
| Within-row spacing (cm) | 22.5 | 22.5 |
| Between-row spacing (cm) | 71 | 71 |
| Experimental design | Randomized block | Split plot |
| Number of physiological ages (day-degrees > 4°C) | 8 (i.e. 0, 112, 224, 336, 448, 560, 704, 816) | 6 (i.e. 0, 168, 336, 504, 672, 840) |
| Irrigation treatments | Nil | No supplementary irrigation; trickle irrigation to maintain soil moisture deficits < 30 mm |

the end of storage, number and length of sprouts were recorded on ten randomly selected tubers in each replicate of all treatments.

The experiments were planted at Trefloyne, Tenby, southwestern Wales on Devonian Sandstone soils of the Milford Association (Soil Survey of England and Wales, 1984). Experiment 1 was planted in ridges and experiment 2 on the flat using hand spades. In experiment 2 a split plot design was used with two irrigation treatments as main plots, no supplementary water and trickle irrigation to maintain soil moisture deficits below 30 mm. Water use was measured with a neutron probe on plots of 0 and 840 day-degrees > 4°C and the amount of water to be applied to other plots was determined by comparison of their leaf area indices with those of the recorded plots. There was little rainfall from mid-April to late May in 1980 and on 18 May all irrigated plots in experiment 2 received an application of 30 mm of water. On 7 June a further 30 mm of water was applied to plots of 0—504 day-degrees > 4°C and 20 mm to the two oldest treatments. There was sufficient rainfall for the remainder of 1980 to maintain soil moisture deficits < 30 mm and no further applications of water were made. There were no symptoms of blight or virus diseases in either experiment.

Emergence and number of above-ground stems were recorded at weekly intervals or less using one harvest row and growth analysis samples were taken using three plants per plot on three occasions early in growth in both experiments as described by Allen (1977) and O'Brien et al. (1983). Great care was taken to ensure that as much of the root system as possible was dug from the soil beneath the sampled plants. Tuber yield was assessed on three occasions using a 2.7-m length of row in both experiments; the final harvest was taken when senescence was complete in all plots. Methods of harvesting and grading were as described by Allen (1977).

With the exception of May 1979 (experiment 1) and June 1980 (experiment 2) which were dull, average or above average sunshine prevailed throughout the summer months in both years. Although there was little rainfall in July 1979, sufficient rain fell throughout the remainder of the season to maintain growth up to late July.

## RESULTS AND DISCUSSION

### *Sprout growth*

Fig. 1 shows that in each experiment there was a close positive linear relationship between length of the longest sprout per tuber at the end of storage and number of day-degrees > 4°C. These and similar relationships in other varieties in many experiments (O'Brien et al., 1983) suggest that the effects of pre-planting environment on sprout growth may be summarized by accumulated day-degrees. The variation in the slope of the lines in the 2 years was mainly due to the effects of slight etiolation of sprouts in the longer periods of high temperature storage in 1979.

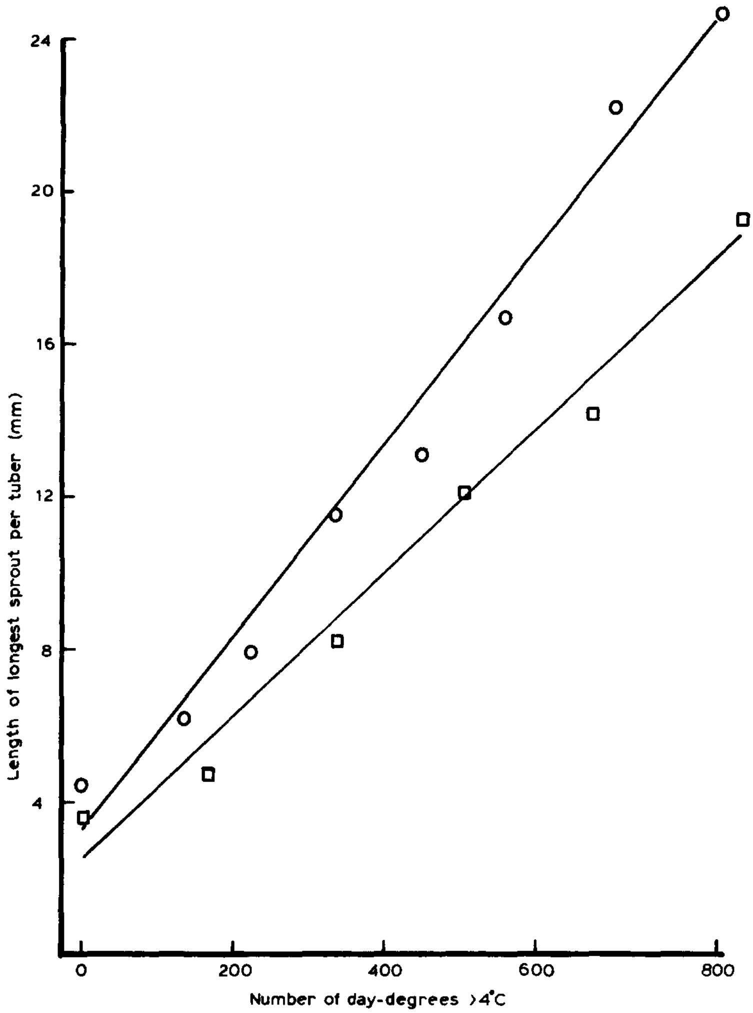


**Fig. 1. Relationship between length of the longest sprout per tuber at planting and number of day-degrees > 4°C in 2 years. ○, 1979 (experiment 1) $y = 3.25 + 0.0254x$, $R^2 = 0.98$; □, 1980 (experiment 2) $y = 2.43 + 0.0189x$, $R^2 = 0.98$.**

*Field growth*

In both experiments, increasing the number of day-degrees > 4°C experienced by seed tubers hastened plant and stem emergence but once stem populations had stabilized there was little effect of number of day-degrees > 4°C on the total number of stems (Table 2). There were, however, effects on the types of stem comprising the total stem population. With increasing number of day-degrees > 4°C of seed tubers, number of main-stems decreased over the whole range, while number of secondary stems increased up to intermediate values and usually decreased slightly with

TABLE 2

**Effects of physiological age on number of emerged plants, number of above-ground stems, number of mainstems and number of secondary stems (000's/ha)**

| | Number of emerged plants | Number of above-ground stems | Number of mainstems | Number of secondary stems |
|---|---|---|---|---|
| Experiment | 2 | 1 | 1 | 1 |
| Date | 21 April | 6 July | 6 July | 6 July |
| Number of day-degrees > 4°C | | | | |
| 0 | 0.0 | 175.0 | 158.3 | 16.7 |
| 112 | | 162.5 | 133.3 | 29.2 |
| 168 | 1.6 | | | |
| 224 | | 177.1 | 116.7 | 60.4 |
| 336 | 5.7 | 212.5 | 110.4 | 102.1 |
| 448 | | 220.8 | 137.5 | 83.3 |
| 504 | 38.5 | | | |
| 560 | | 212.5 | 116.7 | 95.8 |
| 672 | 35.4 | | | |
| 704 | | 175.0 | 104.2 | 70.8 |
| 816 | | 216.7 | 89.6 | 127.1 |
| 840 | 37.0 | | | |
| S.E. | 5.14 | 13.52 | 13.32 | 17.2 |

further increase in number of day-degrees > 4°C (Table 2). Early in growth, leaf area index increased with increasing number of day-degrees > 4°C up to 672 and then decreased slightly with further increase in accumulated day-degrees (Fig. 2). After early June negative relationships were found between leaf area index and number of day-degrees > 4°C. Thus, seed tubers with few day-degrees > 4°C produced smaller leaf canopies early in growth and larger canopies later in growth than seed tubers with the greatest number of day-degrees. Similar effects changing with time were found in root dry weight (Fig. 3), plant dry weight and tuber yields.

Close relationships between tuber yields and numbers of day-degrees > 4°C were found at all harvests in both experiments, and the relationship changed from positively linear at the earliest harvest in experiment 1 to negatively linear at the final harvest in both experiments (Fig. 4). For the remainder of the harvesting period negatively quadratic relationships fitted the data best and the optimum number of day-degrees for tuber yields decreased with delay in harvesting.

It is particularly noteworthy that the closeness of fit of the regressions was high and emphasises the direct influence of number of day-degrees > 4°C experienced by seed tubers on leaf growth and hence tuber yields.

These data and those reported earlier (O'Brien et al., 1983) support

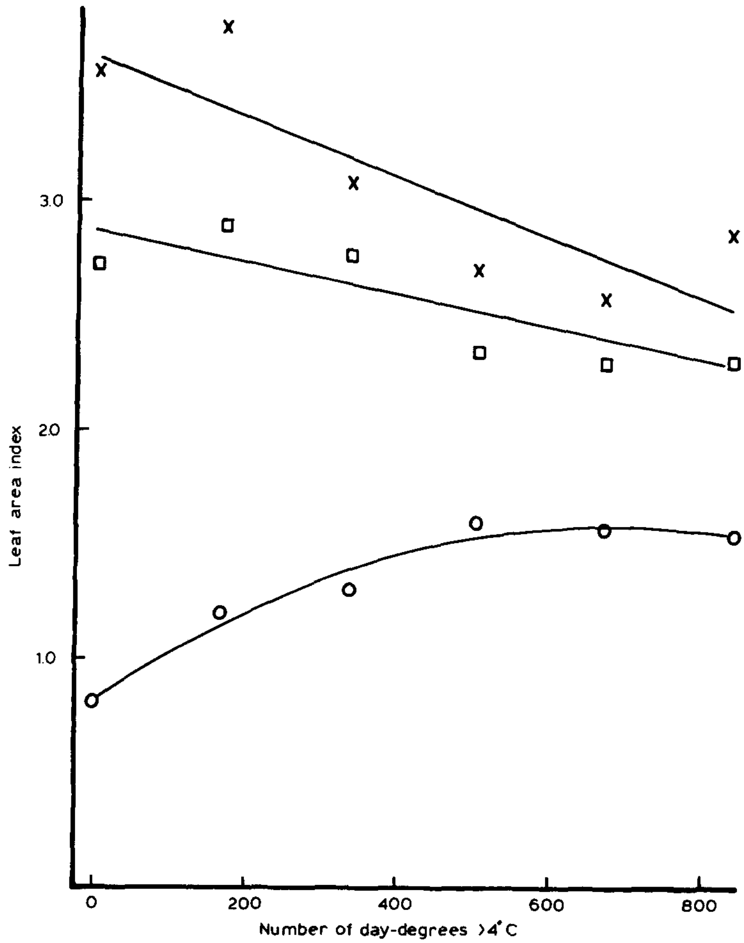


Fig. 2. Relationship between leaf area index and number of day-degrees > 4°C in experiment 2. ○, 20 May, $y = 0.82 + 0.0023x - 1.66 \times 10^{-6}x^2$, $R^2 = 0.97$; □, 5 June, $y = 2.86 - 0.007x$, $R^2 = 0.74$; ×, 25 June, $y = 3.62 - 0.0013x$, $R^2 = 0.70$.

the use of day-degrees > 4°C from end of dormancy to end of storage as an effective and practical measure of physiological age of seed potato tubers and indicate that optimum ages can be determined for specific periods of harvesting.

## DISCUSSION

The results show that there were close relationships between all aspects of sprout and field growth and accumulated day-degrees which justify the use of this quantitative scale as a measure of physiological age. The effects were consistent in the two seasons and therefore optimum physiological ages of seed tubers for specific periods of harvesting can be deter-

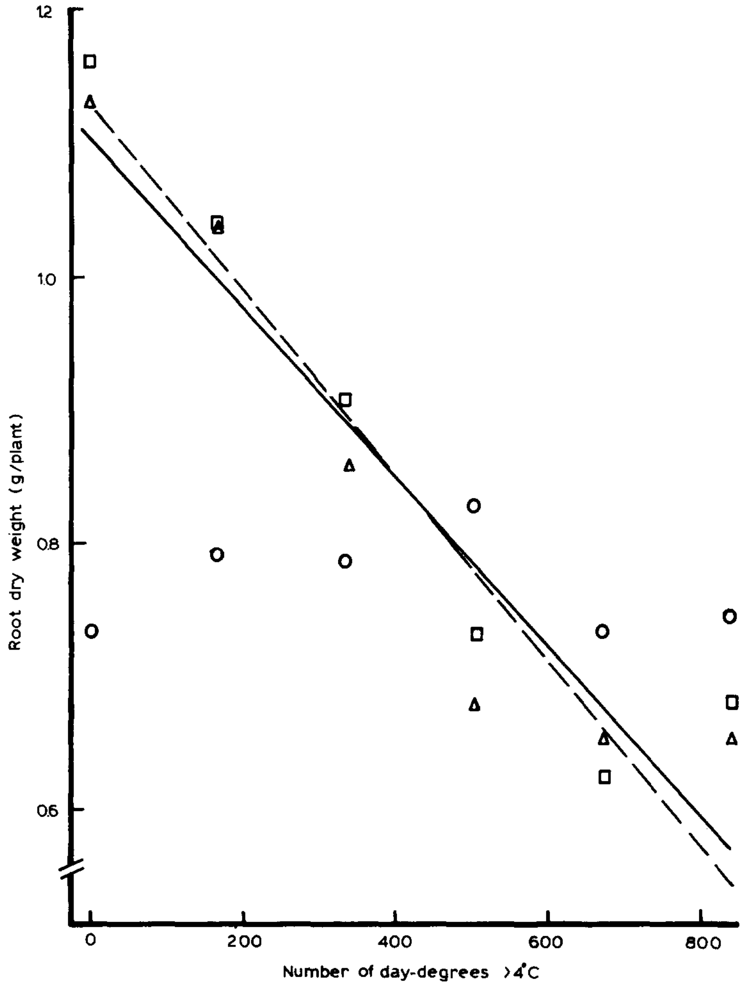


Fig. 3. Relationships between dry weight of roots in the top 25 cm of soil and number of day-degrees > 4°C, Pentland Javelin (experiment 2). ○, 20 May; □, 5 June, $y = 1.129 - 0.0007x$, $R^2 = 0.91$; △, 25 June, $y = 1.103 - 0.0006x$, $R^2 = 0.90$.

mined. Similar effects have subsequently been found in a wide range of varieties so that the basic pattern of effects appears consistent. If control of sprouting temperatures is available, seed tubers of the optimum physiological age can be produced by a specific date in all seasons. Without such control the physiological age of seed tubers will be determined by the prevailing temperatures which may show considerable variation. The value of this temperature-based scale is that it is simple to record and allows the pre-planting effects of seed-tuber production and storage conditions to be summarized through the timing of the ending of dormancy and the storage temperatures. It is, therefore, a practical measure and is meant to be used by growers.

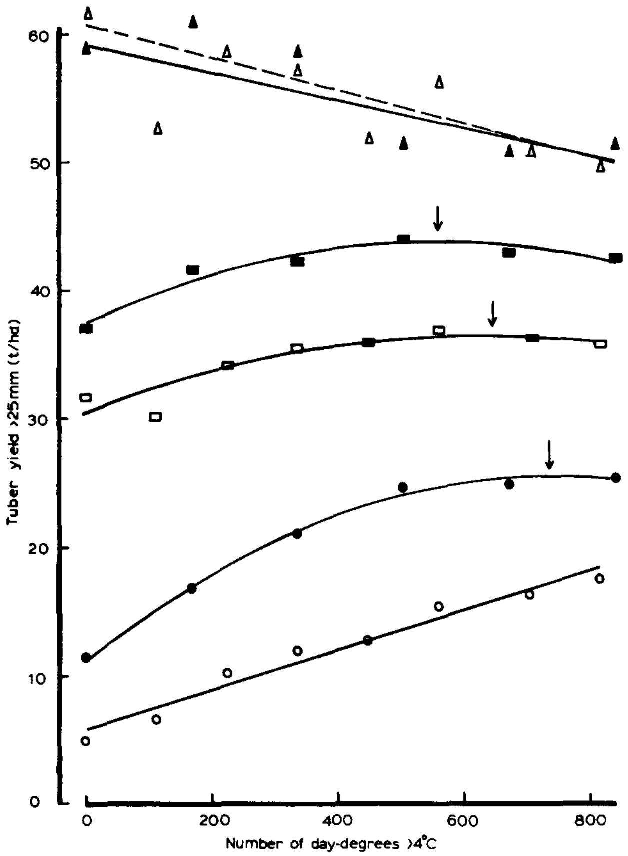


Fig. 4. Relationships between tuber yield > 25 mm and number of day-degrees > 4°C in experiment 1 and 2. ○, 22 June 1979, $y = 5.75 + 0.0154x$, $R^2 = 0.96$; □, 6 July 1979, $y = 30.4 + 0.0187x - 1.45 \times 10^{-6}x^2$, $R^2 = 0.83$; △, 15 August 1979, $y = 59.1 - 0.0108x$, $R^2 = 0.53$; ●, 7 June 1980, $y = 11.34 + 0.0382x - 2.59 \times 10^{-5}x^2$, $R^2 = 1.00$; ■, 25 June 1980, $y = 37.5 + 0.0223x - 2.00 \times 10^{-5}x^2$, $R^2 = 0.93$; ▲, 4 August 1980, $y = 60.7 - 0.0127x$, $R^2 = 0.76$; ↓, optimum number of day-degrees.

The results refer to seed tubers planted without desprouting and it is not possible to relate them to published work which involved the desprouting of tubers prior to planting (Madec and Perennec, 1955; Madec, 1958). Such confounding of effects is avoidable and in further experiments it has been found that desprouting effectively removes any effects of physiological aging (O'Brien and Allen, 1984). This implies that the effect of physiological aging is carried in the sprout and not in the tuber as has been previously reported (Madec and Perennec, 1955; Madec, 1958). Seed tubers without sprouts, whether from cold storage or after desprouting, are therefore effectively at 0 day-degrees and it is not known if all seed tubers planted in this condition grow and yield in the same way. No papers allow the appropriate comparisons to be made but O'Brien and Allen (1981) argued that the expectation from the type of relationships presented in this paper is that no differences would be found. O'Brien and Allen (1984) and unpublished data from the continuing series of experiments at Trefloyne (and Cambridge) suggest that this expectation is valid. Thus, healthy seed stocks planted without sprout growth may be regarded as a homogeneous population. Further, if accumulated day-degrees for the growth of the sprouts actually planted are used, the measure appears independent of effects prior to the onset of growth of these sprouts.

The utility of this measure of physiological age is probably specific to seed tubers stored for upto 8--9 months before planting i.e. the normal circumstances for Northwestern European potatoes. Longer periods of seed storage may result in physiological deterioration associated with excess chronological age as found by Kawakami (1952). In Northwestern Europe most tubers are planted some months after the end of dormancy and the performance of seed planted close to the end of its dormancy may not be predicted by this measure. This would occur in Mediterranean areas where seed from Northern Europe may be planted before the end of the year of seed production. In these circumstances the tuber is in the one-sprout condition described by Krijthe (1962) and may produce a plant of few or only one stem when planted. This may explain why the preferred varieties are maincrops but are grown primarily for earliness. However, there are no data to substantiate this view; in these circumstances accumulated day-degrees are unlikely to be of any relevance in understanding the physiology of seed tubers. In maincrop varieties with long dormancies it is possible to envisage planting close to the end of their dormancy in Northwestern Europe and in such circumstances the production of single-stemmed plants would probably be disadvantageous. There would have to be an increase in seed rate to achieve an appropriate number of stems and in these circumstances any treatment which increased number of stems per seed tuber would be beneficial e.g. desprouting. Again in these circumstances the use of accumulated day-degrees would be of no relevance. In these two cases it clearly could occur that young seed tubers would have single stems as a consequence of planting close to the end of dormancy but there would be no "old" seed tubers in these circumstances. The confusion over the terms "old" and "young" exemplified by the work of Bus and Schepers (1978) arises because of the failure to appreciate that seed tubers in the single-sprout phase are young at that time but cannot remain young if the sprout grows for 3—5 months. Thus, within the specific circumstances of Northwestern Europe and varieties of relatively short dormancies, the use of accumulated day-degrees provides a repeatable and easily used measure of seed-tuber physiological age. In other circumstances the state of the seed tuber and its likely performance require other measures.

The results showed very close relationships between leaf area index and physiological age throughout the season and emphasise the major effect that seed-tuber storage has on the growth of the leaf surface. The close relationships between tuber yields and physiological age were to be expected in view of the effects of seed-tuber physiological age on leaf growth and a major and potentially productive task for future research is to identify the component aspects of leaf growth which are affected by the physiological age of the seed tuber.

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