STUDIES ON SOLANUM TUBEROSUM L.

WITH SPECIAL REFERENCE TO STORAGE AND FACTORS AFFECTING SUCCESS IN THE FIELD.

A Thesis submitted to the University of Edinburgh
for the Degree of Doctor of Philosophy

by

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PART I.

THE EFFECT OF ENVIRONMENT ON TUBER BEHAVIOUR DURING THE PERIOD OF STORAGE AND THE SUBSEQUENT EFFECT OF STORAGE IN THE FIELD.

INTRODUCTION.

A potato tuber is the modified apex of a stem adapted as a storage organ for the purpose of vegetative reproduction and perennation. This apical region has shortened internodes, greatly swollen, and at the nodes, weakly developed lateral members commonly called 'eyes'. Being a living entity the tuber is highly responsive to vagaries of the factors of the environment obtaining during storage and these may determine its condition as regards soundness, viability, cooking quality and tuber behaviour when planted as seed. With the modern introduction of storage in sheds and under controlled temperature as opposed to older and more primitive methods, detailed knowledge is required regarding all influencing external factors in their various combinations and in their ultimate effects. To this end the following experiments were carried out and observations made as no overall story of these intricate relationships can be found in the available literature. There is a need of fundamental knowledge on the subject to enable the reports and results of field work to be analysed in their true perspective. This is true also from an economic point of view when sheds are being erected or adapted as controlled temperature stores, in order to ensure that the stored crop will be in the best possible conditions to suit the ultimate aim for the conserved product.

Previous work has been based almost entirely on the belief that the potato tuber has a period of enforced rest after harvest. From the available literature on the subject the main concern of the authors has been to measure the length of this enforced rest period, which was submitted to be totally independent of the environmental conditions within the temperature limits of viability, to measure the length of the extended rest period (dormancy) due to environmental conditions only, to study the factors which govern the length of these periods and to find physiological reasons for them. The authors and their findings will be referred to in the text where it is appropriate. No fundamental work appears to have been done specifically on the effect of environment on sprout growth or on the subsequent effects of storage in the field, only observations from commercial crops in different manners of storage.

During the course of the experimental work it was found that there were two stages during the period of storage when the reaction of the tuber was different to the same environmental influence. The first stage (Sub-section A) is the period from harvest to minimal visible sprouting and the second stage is the remaining period of storage (Sub-section B). "Minimal visible sprouting" is here defined as that point in time after harvest when a sprout on a tuber is first visible to the naked eye. For the sake of convenience it will be referred to in the text as "M.V.S.". The effect of storage on the subsequent development in the field is dealt with in Sub-section C and in Sub-section D a physiological condition which is in part due to storage is discussed.

A. Dormancy and the Period Extending from Harvest to the Point of Minimal Visible Sprouting.

Introduction.

In any study of storage, dormancy is the phenomenon of fundamental importance. A widely held view is that the potato tuber has a 'rest period'. This has been defined as 'that period immediately following harvest during which the potato tuber will not sprout even under optimal sprouting conditions'.[(1), (2)] The criterion of the end of the 'rest period' in this case is a visible sprout of approximately 2 mm. in length. An anomaly is apparent in this system in that growth is obviously taking place during the 'rest period' if the sprout must attain the length of 2 mm. before the period is considered over. In less favourable conditions for sprouting the tuber requires a longer period to sprout. This has been termed as the 'dormant period' and defined/

defined as 'that period, during which the tubers may be stored at some temperature suboptimal for sprouting without beginning to sprout or break down physiologically'.[(1), (2)] These views concerning "rest period" and "dormancy" were first submitted by Wright and Peacock[(1)] and substantiated in a comprehensive study by Emilsson.[(2)] To measure the length of the "rest period" Emilsson stored tubers at 41°F. in lots, from each of which samples of ten tubers were drawn every week for transferral to a sprouting room at 70°F. associated with a high relative humidity. In the sprouting room each sample was kept for two weeks and if all the tubers had not sprouted by the end of the period, the sample was discarded. The number of weeks elapsing from the time of harvest till the first sample to have all ten tubers with sprouts 2 mm. or more in length after two weeks in the sprouting room was called the "rest period". The treatment, it will be noted, did not fulfil the requirements of the definition as the tubers were not stored in "optimal sprouting conditions", being held at 41°F. which is well below the best conditions for promoting sprout growth; and when samples were transferred to more propitious sprouting conditions they were given only two weeks for the sprouts to develop. The figures obtained range from five to fifteen weeks for the so-called "rest period" when tubers would be incapable of sprouting even in "optimal sprouting conditions". It will be shown here that the potato tuber has no "rest period" and that the appearance of a readily visible sprout is not a sign of the break in dormancy but the first visible indication of growth which has been progressing, albeit slowly, from the time of harvest.

Dormancy Experiment.

Method. In the case of the potato tuber "M.V.S." has been regarded as the critical sign of the commencement of growth or the end of the dormant period. In order to study the possibility of growth proceeding for some time prior to M.V.S. a number random samples each of ten tubers and all from the same plot of the variety "Majestic", were lifted at haulm maturity and stored in two batches at constant temperatures. One at 80°F. (±5) and the other at 39°F. (±2). A ten-tuber sample from each storage environment was examined periodically and the lengths of the median-longitudinal section of the sprout initials of the apical eyes were measured, using a micrometer eye-piece.

Results. The readings for such experiments conducted during two seasons are shown in Table 1 and the mean readings are shown graphically in Figure 1.

TABLE/

TABLE 1.

Length of the Median-Longitudinal Section of Sprout Initials of the Apical Eye of Tubers under Storage from Harvest to Minimal Visible Sprouting.

Storage at 80°F. (± 5).

	1956.					1957.						
Sample	1 (at harvest)	2	3	4	5	1 (at harvest)	2	3	4	5	6	7
Date	26/9	1/10	3/10	8/10	10/10	24/9	27/9	2/10	4/10	7/10	11/10	23/10
	.44	.45*	.27	.45	.2	.15	.3	.19	.35	.7*	.43*	.7*
	.29	.5	.35	1.09*	.3	.15	.2	.42	.42	.22	.43*	.9*
	.2	.3	.4*	.45	.6*	.2	.4	.2	.25	.28	.5*	.7*
	.34	.45*	.28	.25	.2	.31	.15	.2	.42	.3	.5*	.6*
	.1	.25	.7*	.5*	.45*	.1	.22	.23	.30	.4	.48*	1.0*
	.2	.15	.3	.3	.88*	.1	.3	.31	.2	.45*	.63*	.8*
	.15	.6*	.47	.7*	.76*	.18	.32	.23	.2	.4	.43*	.75*
	.26	.1	.23	.3	.75*	.2	.2	.23	.24	.33	.6	.8*
	.15	.2	.5	.3	.23	.2	-	.2	.35	.4	.28	.65*
	.2	.45*	.4	.9*	.6*	.21	-	.19	.3	.32	.2	.25
Totals	2.33	3.45	3.9	5.24	4.97	1.8	2.09	2.4	3.03	3.80	4.48	7.15mm.
Means	.233	.345	.39	.524	.497	.18	.26	.24	.303	.38	.448	.715mm.

Storage/

* Asterisk denotes sprouts visible to the naked eye.

Table 1 (Contd.)

Storage at 39°F. (± 2).

1956.

Sample	1 (at harvest)	2	3	4	5	6	7
Date	26/9	18/10	6/11	16/11	26/11	10/12	17/12
	.44	.31	.1	.32	.3	.3	.4
	.29	.18	.3	.35	.34	.3	.4
	.2	.2	.2	.41	.4	.15	.3
	.34	.3	.15	.4	.35	.35	.6*
	.1	.15	.15	.15	.2	.95*	.2
	.2	.25	.2	.6	.2	.5*	.45
	.15	.2	.2	.32	.37	.45	.95*
	.26	.28	.38	.2	.3	.3	.43
	.15	.14	.2	.25	.5	.3	.5
	.2	.2	.2	.2	.6	.3	.45
Totals	2.33	2.21	2.08	3.2	3.56	3.9	4.68
Means	.233	.221	.208	.32	.356	.39	.468

* Asterisk denotes sprouts visible to the naked eye.

1957.

1 (at harvest)	2	3	4	5	6	7	8	9
24/9	7/10	18/10	25/10	1/11	11/11	19/11	5/12	14/12
.15	.28	.15	.26	.32	.3	.4	.4*	.45*
.15	.3	.25	.2	.25	.22	.25	.4	.38
.2	.3	.35	.19	.19	.4	.3	.62	.47*
.31	.4	.3	.3	.2	.44	.29	.45*	.32
.1	.3	.1	.33	.22	.2	.5*	.29	.44
.1	.18	.28	.35	.25	.28	.2	.35*	.6*
.18	.2	.23	.32	.2	.2	.45*	.36	.45*
.2	.3	.2	.15	.37	.38	.4*	.33	.5
.2	.2	-	.2	.58	.33	.45*	-	-
.21	.28	-	.3	.45	.2	.39	-	-
1.8	2.74	1.86	2.6	3.03	2.95	3.63	3.2	3.61
.18	.274	.23	.26	.303	.295	.363	.4	.45

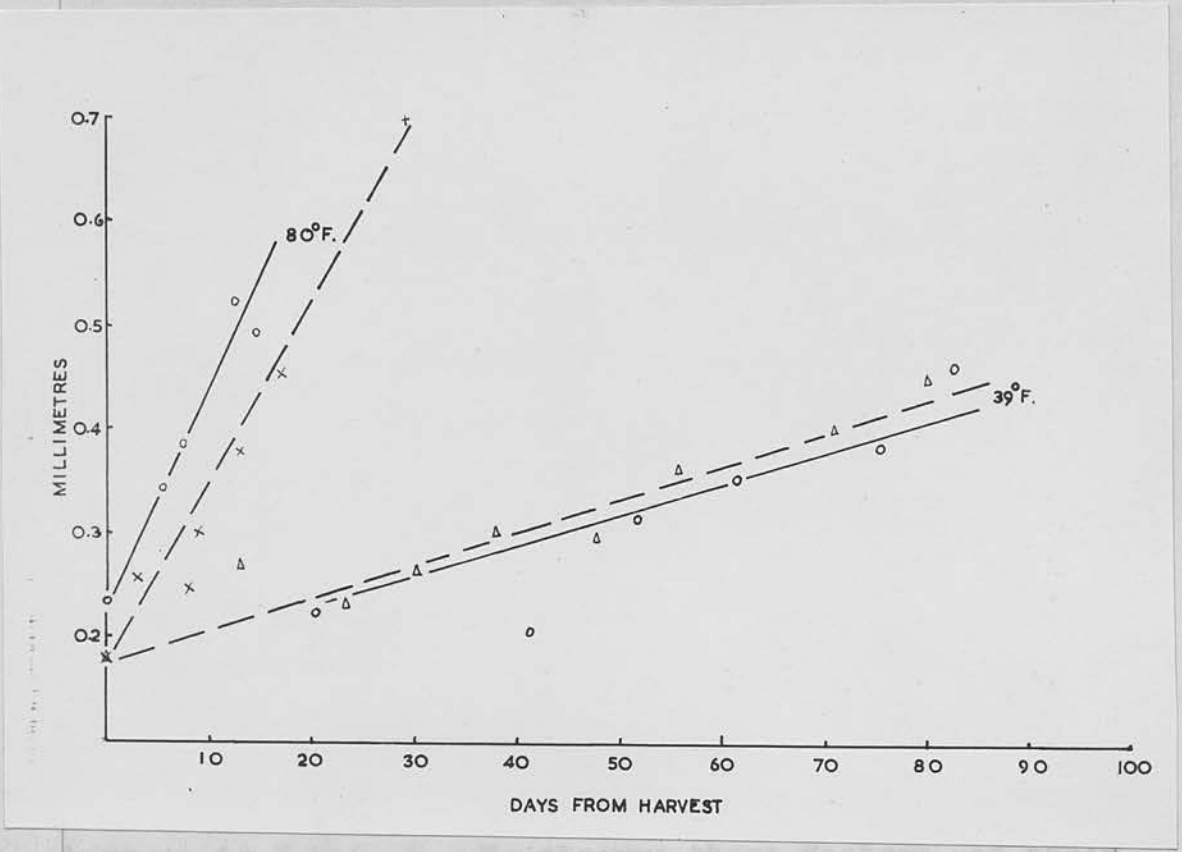

Figure 1. The Growth of the Apical Eye Sprout-Initials of Potato Tubers (Variety Majestic) from Harvest to the Stage of Minimal Visible Sprouting. Each Point on the Curves Represents Measurements Obtained from a 10-Tuber Sample.

____________ 1956 - - - - - - - - - - - 1957.

Figure 1 shows that in tubers stored at 80°F. growth of the sprout initials proceeds rapidly, reaching/

reaching M.V.S. after two weeks in storage. This proves that there is no incapacity for growth. On the other hand, during storage at 39°F. growth proceeds slowly at the sprout initials. When the sprout-initial attains a length of approximately .45 mm. it becomes visible to the naked eye as a sprout. As the length of the sprout-initial at harvest is in the region of .2 mm., the increase of .25 mm. occurs within the period of apparent tuber dormancy. (Appendix 1).

Minimal Visible Sprouting Experimental Sequence.

Methods and Results.

Having substantiated that the potato tuber has no enforced 'rest period', the question remains, what factors govern the length of the period required from harvest to V.M.S. ? To observe these factors and their effects, the following experimental sequence was carried out.

Fourteen varieties were selected, comprising four first earlies, seven maincrop and three late maincrop, for use in the first experiment. The stocks of these were known to be free from virus and other diseases and were grown in adjacent plots, each accommodating thirty plants. The plots were harvested at haulm-maturity except in the case of the three late varieties noted in Table 2, which were harvested after the haulms had been killed by frost. The season was a good one for/

for potatoes, being dry and warm. No blight (Phytophthora infestans (Mont.)de Bary.) or other diseases was observed on the haulms or tubers.

Some 'second-growth' was evident in the crop, the causes of which will be discussed later.

The tubers harvested from each variety were divided into four equal lots of from fifty to one hundred tubers and placed under different storage conditions. Chambers maintained at reasonably constant temperature were used except in the case of "normal shed storage". The chambers were adapted from two small sections of an aphid-proof greenhouse. A third was also used for later experiments. These were insulated on the outside with sacking under slatted blinds and on the inside of all the glass with sheets of thick brown paper pinned to the wooden frames. The thermostatic controls of these chambers were set to give a mean temperature of 80°F. and 68°F. respectively. The actual figure for each day was recorded, the variation in each case being within the region of ± 5°F. The humidity within both chambers was kept as high as possible by draping damp sacks over the sprouting boxes and by having trays of water on the floors. A cold store at a temperature of 35°F. (± 2°F.) was used to store tubers in unfavourable conditions for sprouting. The approximate relative humidity is given in Table 2, but it will be shown later that humidity and also light have no influence on the length of the period from harvest to M.V.S. at least in the higher range of temperatures. The results are shown in Table 2.

Table 2.

Days from Harvest to Minimal Visible Sprouting of Tubers in Different Storage Conditions.

Variety	Maturity	Harvest Date	Average Days to Sprouting			
			90-95% Humidity		Normal Shed Storage at Concurrent Air Temps. & Humidity with Heating During Frost	95-100% Humidity
		1955	80°F	68°F		35°F
Epicure	1st	20/8	45 ≠ (33)	64	97 (75)	177(101)
Ulster Chieftain	Early	29/8	46	57	97	136
Home Guard		29/8	28	34	-	73
Arran Pilot		10/9	39	47	68	82
Record		16/9	32	46	87	109
Arran Consul		11/10	30	43	135	150
King Edward		13/10	28	32	89	141
Orion		19/10	31	39	100	138
Dr. McIntosh	Early	19/10	13	21	47	87
Majestic	Maincrop	19/10	21 (22)	41	89 (80)	136(120)
Redskin		20/10	20	22	69	136
ж Kerr's Pink		20/10	13	20	45	84
ж Golden Wonder	Late	20/10	38	39	117	151
ж Up to Date	Maincrop	20/10	20	22	65	93

≠ Bracketed figures are for a second year of test.
ж Haulms killed by frost.

The Factors Which Govern the Length of the Period of Storage to M.V.S.

The behaviour of plants is governed by the reaction of their genetical potentialities to the factors which make up their environment. The length of the period from the time of harvest to M.V.S. in the potato tuber is controlled in this manner and the following is an account of the individual factors and their influence.

a. Physical Factors.

Temperature. The temperature of storage appears to be the primary factor of the environment influencing the length of the storage period to M.V.S. Tubers can survive after treatment at a surprisingly high temperature. About half of a number of fresh tubers subjected to eight hours in an oven at 120°F. survived. Following such treatment the survivors show death of the pith tissue and occasionally death of small areas of the cortex but the tubers sprout and, on planting, produce apparently normal plants. Such symptoms have been found from time to time in commercial samples and are then taken to be a sign that extreme heating has occurred in the clamp. The condition is called 'Black heart'. At low temperature tubers stored for a month or two at 32°F. are subject to a breakdown of the flesh which turns a reddish brown colour. Actual freezing with the subsequent death of the tissue occurs at 28°F.

Temperature is the primary factor in controlling the period to M.V.S. That giving the shortest period being in the neighbourhood of 80°F. where the average time from harvest to M.V.S. was twenty-nine days and that giving the longest period 35°F., where the average to M.V.S. was one hundred and twenty days (Figure 2).

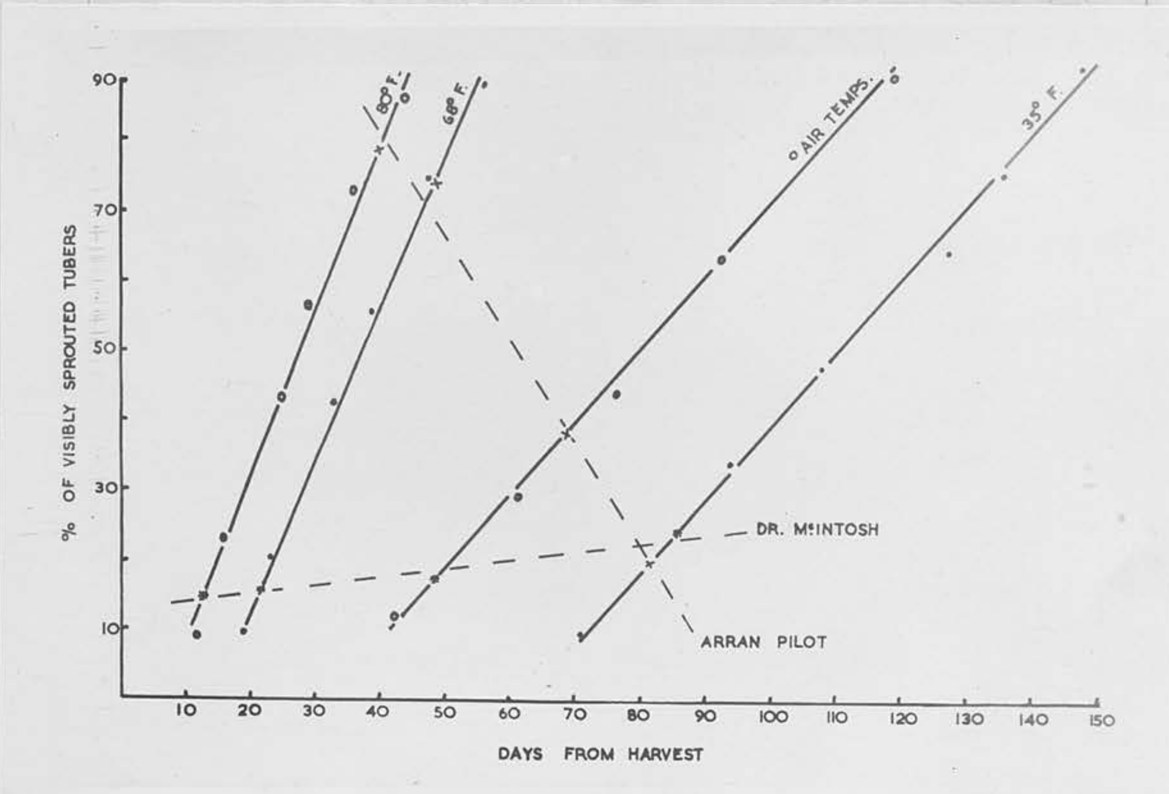

Figure 2. Days from harvest to minimal visible sprouting for tubers of fourteen varieties, comprising approximately one thousand tubers per storage condition. The curve air temperatures is for tubers stored in a shed at concurrent air temperatures above freezing point. The different between varieties in their reaction to different storage conditions is shown by the plotted paths of two varieties ("Arran Pilot" and "Dr. McIntosh").

Humidity. The humidity of the store has no apparent effect on the length of the period to M.V.S. at high temperatures (Table 3) but may have some effect at lower temperatures of storage, although this is thought to be slight. Emilsson found a significant shortening of the 'rest period' at 68°F. with 100 per cent humidity.(2)

Light or Dark Conditions. These conditions have no effect on the length of the period to M.V.S. at high temperatures (Table 3) and it is thought to have no effect at lower temperatures. Since the sprout is not visible to the naked eye during this period, little, if any, light will penetrate to the sprout initials and hence the lack of influence.

TABLE 3.

The Effect of Humidity and Light on the Length of the Storage Period to Minimal Visible Sprouting for Samples of 250 Tubers in Storage at 80°F.

Storage Conditions	Average Storage Period in Days to Minimal Visible Sprouting		
	Dark Relative Humidity 40%	Light Relative Humidity over 90%	Dark Relative Humidity over 90%
Variety			
Epicure (1st Early)	33	33	33 ✓(45)
Majestic (Main crop)	26	21	22 (21)

✓ Second year of test.

Chemical/

Chemical Treatment. Many treatments with chemicals are known to shorten the period of storage to M.V.S. (dormancy breaking). Ethylene chlorhydrin has proved to be the most efficacious and has been used commercially.(3) Tubers of the variety "Great Scot" were lifted at haulm-maturity and treated with ethylene chlorhydrin (0.5 cc. per litre air space for forty-eight hours) immediately after harvest and stored in lots of forty tubers at 80oF., room temperature 60°F. and 35°F. The results in Table 4 show that ethylene chlorhydrin shortens the period from harvest to M.V.S. in all storage conditions. The effect on subsequent sprout growth will be discussed later.

TABLE 4.

The Effect of Ethylene Chlorydrin on Samples of Forty Tubers, Each in Three Different Temperatures of Storage.

Variety	Date of Harvest	Treatment	Average Number of Days from Harvest to Minimal Visible Sprouting		
			80°F.	Room Temperature 60°F.	35°F.
Great Scot	5/9	6/9	12	30	58
Do.	5/9	Control	22	52	81

Oxygen. The permeability of the periderm of the potato/

potato tuber has been postulated as a controlling factor of the length of the 'rest period'. The term 'rest period' is used here, and in future in the text when literature in which the term is used is discussed, as defined by Wright and Peacock.[1] Appleman[4] suggested that the 'rest period' depended on the thickness of the periderm of the tuber which under normal conditions becomes suberised and resists the entrance of oxygen, and it is not until a certain balance is reached between the bud tissues and the external oxygen that the 'rest period' is broken. Thornton[5],[6] believed that the supply of internal oxygen is limited by the periderm with increasing effect as the storage period progresses and thickening occurs. The internal oxygen thus becomes in such short supply that the 'rest period' is broken. Emilsson[2] found no relationship between the thickness of the periderm and the length of the 'rest period'. Sawyer and Smith[7] were unable to confirm Thornton's findings and submitted that oxygen *per se* is not the normal factor regulating the 'rest period' of the tuber.

Physiological Factors.

Variety. Experience has shown that varieties differ from one ~~and~~ another in many ways but the behaviour within the variety is relatively stable. Thus the period of storage to M.V.S. is found to be fairly constant; the higher the storage temperature the narrower is the range about the mean date of sprouting. This is in agreement with Appleman.[4] From Table 1 it will be noted that there is a general correlation between the earliness with which a variety ripens and the appearance of a relatively long period being required from harvest to M.V.S. at the higher storage temperatures. Apart from this, the varieties in the trial showed an individual reaction to storage at any particular temperature. In Figure 2 results with two varieties have been plotted to show the difference between varieties in relation to the individual periods of storage required to M.V.S. at different temperatures.

Size of Tuber. Emilsson came to the conclusion that the length of the 'rest period' is shorter in large tubers than in small tubers of the same lot.[2] In these studies this was not confirmed although there was a slight tendency for larger tubers to sprout first.

Degree of Maturity. In all storage conditions immature tubers were found to require a longer period of storage prior to M.V.S. (Figure 3). This agrees with the findings of Emilsson,[2] Wright and Peacock,[1] Koltermann[8] and Rosa.[9]

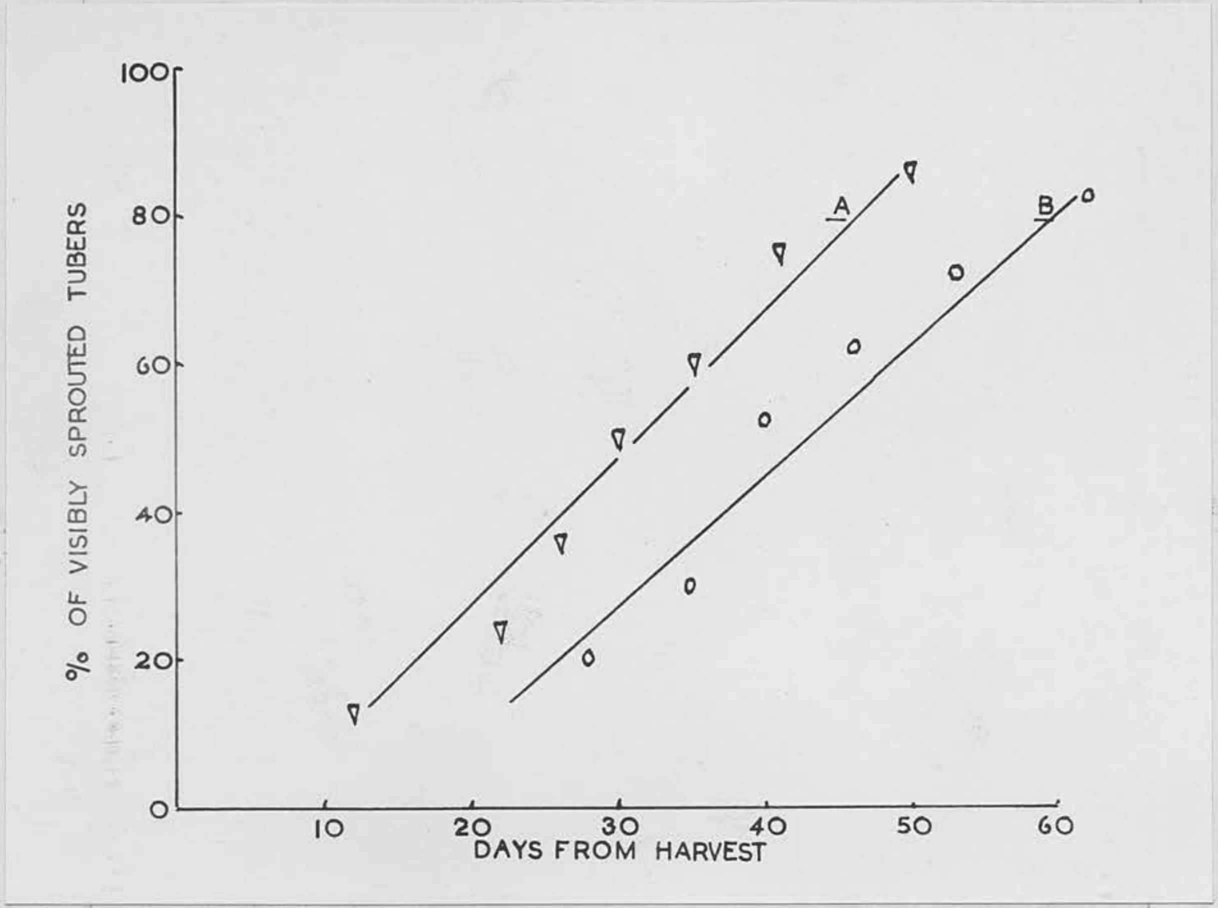

Figure 3. Graph showing the Incidence of Minimal Visible Sprouting of Mature and Immature Tubers from the Same Plots in Storage at 80°F. and at 68°F.
A. Mature tubers. B. Immature tubers.

Starch Content. The variety Golden Wonder is relatively rich in starch and it may be observed from Table 2 that it was outstanding amongst the late maincrop varieties in requiring a longer storage period to M.V.S. in all storage conditions. This confirms the findings of Emilsson.(2) The effect of variation in the starch content of individual tubers within the variety has not been examined but it is believed to be negligible.

Foliage/

Foliage Variants. Tubers of "feathery wildings" were tested against tubers from normal plants of the variety Majestic and in spite of the earlier maturity of the former in the field, little difference from the normals was found in the period of storage to M.V.S. and this at two storage temperatures (Table 5).

Mother Tuber. The storage condition of the mother tuber was found to affect the maturity of the plant in the field but to have no effect on the period to M.V.S. of the daughter tubers.

Parasitic Diseases as Factors.

Fungal Diseases. Tubers infected with dry rot (*Fusarium coeruleum* (Thaxt.) Waksman & Henrici), Blight (*Phytophthora infestans* (Mont.) de Bary.), severe common scab (*Streptomyces scabies* (Lib.), Sacc.) or other organisms have a shorter period of storage to M.V.S. than have healthy tubers of the same variety at the same storage temperatures (Appendix 2a). One qualification is required to be made to this statement, that, in general, the larger the area of infection the greater is the effect. Where there is a small localised infection the effect is inappreciable. Disease of the tuber also affects sprout growth after M.V.S. (Appendix 2b).

Virus Diseases. Generally the presence of viruses in the tubers was found to have little effect on sprouting. An exception was seen in the case of tubers infected with/

with virus "Y". These took appreciably longer than the normal to sprout at both 80°F. and 39°F. (Table 5).

Wounds. Tuber wounds which heal quickly, such as clean cuts and abrasions, have no effect, whereas slow healing or partially healed wounds such as frost damage, are usually accompanied by a certain amount of rot which affects the storage period to M.V.S. in the same way as infection by fungal disease (Appendix 3). It appears that a certain amount of fungal or bacterial rot is associated with the shortening of the period to M.V.S.

TABLE 5.

Average Storage Period in Days to Minimal Visible Sprouting for forty Tuber Samples of Various Potato Virus Diseases and Conditions of the Variety 'Majestic'.

Condition of the Tubers	Maturity Date	Storage Condition	
		80°F.	39°F.
Normal	24/9	22	74
"Feathery Wilding"	6/9	17	87
Leaf-roll	20/9	35	78
Virus "Y"	20/9	40	111
Damaged Tubers	24/9	20	78

Incidental Observations.

1. Apical Dominance. Dominance of the apical eye of the potato tuber is strong in the early part of the storage/

storage period but becomes progressively weaker towards the end of this period.

2. <u>The Phenomenon of "Second Growth"</u>. Mention must be made of this phenomenon which is of fairly frequent occurrence in potato crops in this country and in N. America. A tuber still attached to a plant entering the stage of senescence will, under the influence of environmental change, from warm dry to warm wet conditions, show sprout development in various forms called 'second growth'. At the same time renewed growth is evident on the haulm in the form of fresh growth from the nodes at the tops of the stems. It will be realised that this is a reaction of the plant as a whole, in the same manner as a partially uprooted potato plant at the same stage of growth will maintain its life as long as possible at the expense of the tubers. Second growth is the response of an almost mature tuber to a renewed flow of storage products from the leaves, and appears to be confined mainly to later maturing varieties. Second growth takes various common forms. (10)

(i) A further swelling of the rose end forming a double tuber with a waist of varying thickness.

(ii) The development of the apical eye or eyes to form stolons which may develop tubers (chain tuberisation) if suitable conditions prevail over a long enough period.

(iii) The development of the eyes (gemmation).

The harvested tubers of the first group sprout normally/

normally in storage except for the immaturity of the rose end swelling. Those of the second and third groups are normal in storage except for the absence of apical dominance; the period to M.V.S. being the same as for the normal tubers of the variety.

There would appear to be a threshold point in the development of tubers approaching maturity when a renewed flow of storage material results in second growth.

Discussion on Dormancy and the Period Extending from Harvest to the Point of Minimal Visible Sprouting.

Visible sprouting or an arbitrary sprout length has been previously regarded as the initial sign of growth commencement from potato tubers. From the above results it has been found that growth appears to be continuous at the apical eye from harvest onwards (Figure 1) and the rate of growth is dependent on the storage temperature alone, light having no effect and humidity having possibly some slight effect only at low storage temperatures. The growth at the apical eye being dependent upon temperature, there is no question of dormancy existing in potato tubers, but only a natural conditioning for perennation from one season to the next. If the term 'dormancy' implies absence of visible growth then the potato tuber may be said to be dormant for periods as long as five months if stored under poor conditions for sprouting, but if the term infers incapacity for growth then the potato tuber has no dormant period.

The appearance of a general correlation between the earliness with which a variety ripens and the appearance of a relatively long storage period required to M.V.S. at 80°F. is interesting (Table 1). This character may be a necessary factor for earlies which, maturing in the height of the summer, should not sprout rapidly in spite of favourable growing conditions existing at, and subsequent to, harvest. This factor may be due to selection by breeders and growers or possibly by a natural selection of genes, where an early variety in natural conditions would sprout and grow into a young plant to be inevitably destroyed by the first frost of winter. In storage at 35°F. M.V.S. is delayed for up to five months and, as will be shown later, growth thereafter is extremely slow.

As has been observed, the factor governing the length of the period from harvest to minimal visible sprouting is temperature. Until there is sprout growth, the tuber remains firm and turgid and, as might be expected, the humidity of the surrounding atmosphere is not found to affect the length of this period, nor has lightiss any effect until the sprout is visible.

Any disease of the tuber, provided it is active, will markedly shorten the period to M.V.S. at all storage temperatures. This appears to be purely an inherent method of survival.

B. Sprout Growth During the Storage Period Subsequent to Minimal Visible Sprouting.

After M.V.S. occurs, light, humidity and temperature play compensating roles in their effect on sprout growth. Of these temperature is the primary factor, then light and lastly humidity.

Initial Sprout Growth. In order to observe the rapidity of the initial sprout growth in length at different storage temperatures, samples of twenty tubers each of the variety Dunbar Standard were stored at 80°F., 50°F. and at 35°F. The sprouts were measured at frequent intervals using a shadow technique. The apparatus gave a shadow magnification of x 7 and consisted of a light source, condenser, focal point indicator, astigmatic lens and screen. The results obtained are shown in Figure 4. The point of M.V.S. is shown (V.S.) as 0.45 mm.; there is also due to the technique an unobservable period of growth assumed to be approximately 0.55 mm. (Figure 4).

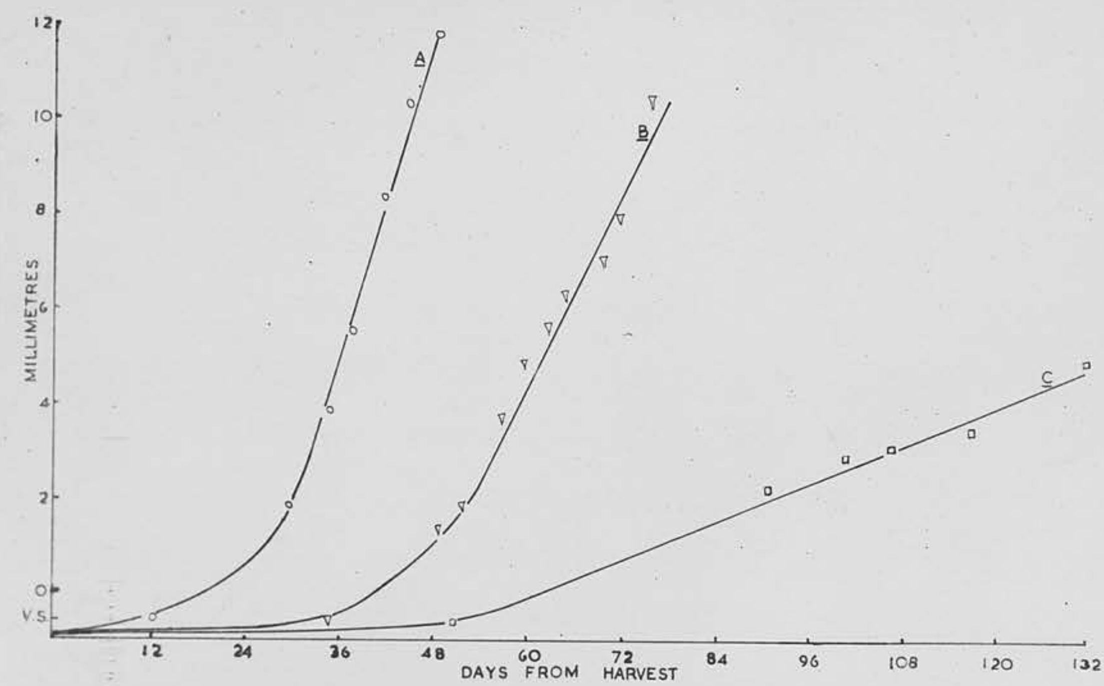

Figure 4. Initial Sprout Growth in Controlled Storage Conditions for the Variety Dunbar Standard. Curve A 80°F.; dark, B 50°F.; dark, and C 39°F.; dark.

Figure 4 shows the growth curves to be sigmoid in pattern and that the rate of the initial sprout growth is determined by the temperature of storage.

Storage at High Temperatures (80°F.). At high temperatures sprout growth is mainly independent of the effects of humidity and light. Sprouts appear within a few weeks of harvest (Table 2) and sprout growth proceeds rapidly for several weeks, by which time the sprouts are approximately three-quarter inch in length (Figure 5). Thereafter the rate of the growth in length/

length slows down and a thickening of the sprout occurs (Appendix 4c), giving eventually a robust thick sprout of approximately one inch in length on a tuber which is wrinkled and rubbery to the touch. The effect of humidity and light may be judged from Appendix 5 where high humidity in dark conditions have promoted growth in the latter part of the storage period.

At 80°F., tubers after treatment with ethylene chlorhydrin (0.5 cc. per litre airspace for forty-eight hours) show an unusual sprout effect. Treated tubers reach M.V.S. and sprout earlier by a few days than untreated tubers. Differences in the rates of growth are not readily apparent until about twelve weeks after treatment. Thereafter growth in length of the sprouts of the treated tubers outstrips those of the normals (Appendix 6). For all practical purposes storage at 80°F. for a few weeks is as efficient a means of 'dormancy breaking' as is the chemical treatment of tubers for immediate planting.

Storage at Room and at Winter Air Temperatures above Freezing Point. In these conditions access to light is the primary factor in controlling sprout growth. M.V.S. occurs on the average about eleven weeks after harvest and thereafter the rapidity of sprout growth is dependent on light access, other conditions being equal. This may be observed in general by comparing typical tubers of Redskin and Up-to-Date after five months' storage in boxes in light at normal air temperatures (Appendix 4A) and tubers of the variety Dunbar Standard after five months' storage at 50°F. in the dark (Appendix 7).

<u>Low-Temperature Storage (35°F.).</u> In low-temperature storage at 35°F. M.V.S. takes place on the average seventeen weeks after harvest and the subsequent sprout growth is slow, with light access, and humidity having, for all practical purposes, only a slight effect up to the end of the normal storage period.

It will be noted (Appendix 4B) that the Redskin and Up-to-Date tubers show M.V.S. after approximately twenty weeks in storage. At the normal planting time in March and April, tubers of all of the sixteen varieties tested over two seasons were sound, with sprouts of one-quarter of an inch or so in length. Tubers stored at 35°F. remain in excellent condition for periods longer than those normally required. The tubers remain sound and sprout growth is very slow (Appendix 8A).

<u>Discussion on Sprout Growth During the Storage Period Subsequent to Visible Minimal Sprouting.</u>

To keep the sprout growth of stored tubers to a minimum is the aim of all growers whether the ultimate use be as ware or seed. At high temperatures of storage the interesting feature is the supreme dominance of the temperature over the effect of humidity and light access on sprout growth. The effect of temperature on the latter being an initial rapid growth in length followed by thickening, there being no etiolation. The sprout is strong and sturdy at the end of the storage period but the tuber is wizened (Appendix 4A). Storage of tubers at high temperatures has no practical significance except for speeding on sprout growth immediately after harvest; but they may be stored at high temperatures and the effects of such storage have some significance is possible in other spheres of investigation. In the middle range of storage temperatures (40 - 60°F.) etiolation of the sprouts occurs in the absence of light, humidity having little or no effect. Sprout growth in length in the absence of light is extremely rapid and continues until the tubers are exhausted. Storage of tubers for ware purposes must be carried out at temperatures below 40°F. and shed stored 'seed' in boxes must have light access. At low temperatures tubers remain during the normal storage period sound, and sprout growth is slow but the pattern of growth is the same as for the 50 - 60°F. range (Appendices 7 and 8B), but extended over a much longer period of time. A graph of the combined effects on sprouting of temperature and light is shown in Figure 5.

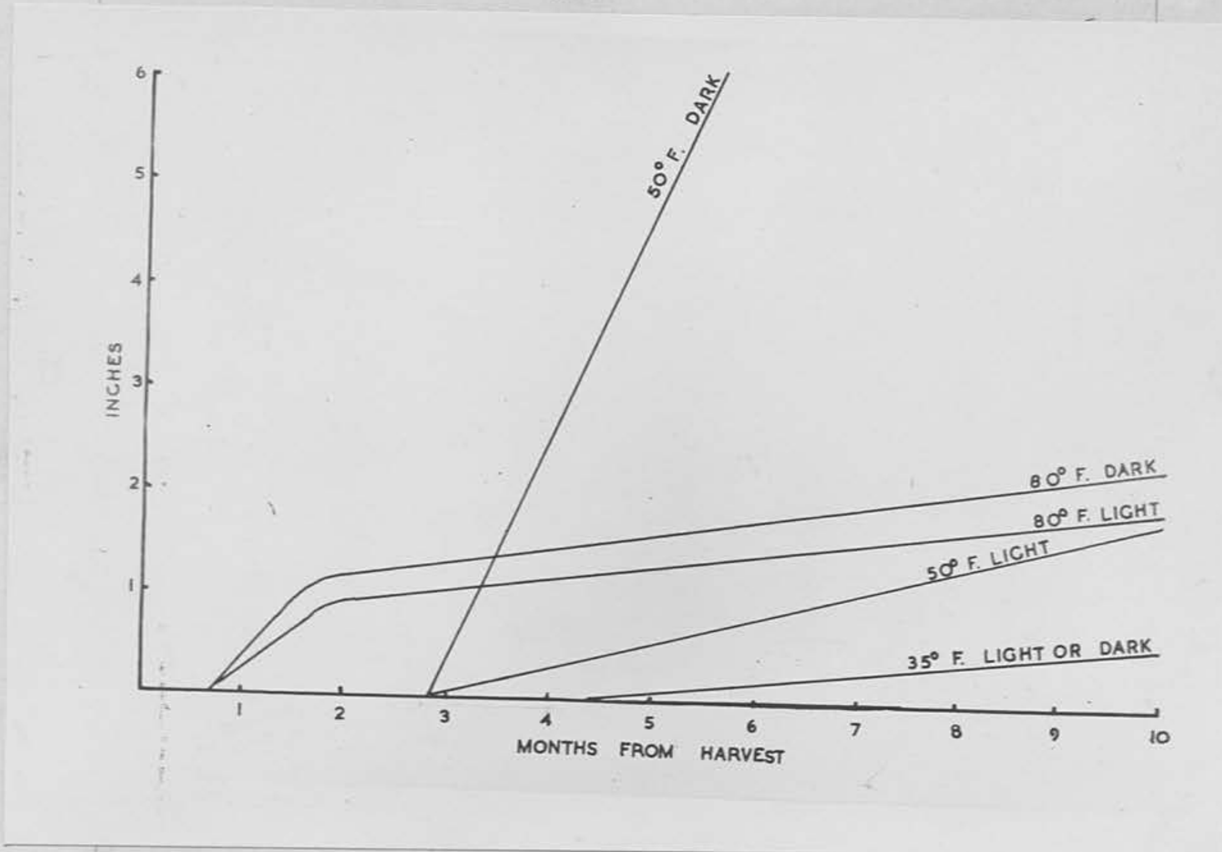

Figure 5. Graph of the Combined Effects of Temperature and Light on the Rapidity of Sprout Growth in Length.

Humidity plays only a minor role in increasing the rapidity of sprout growth.

The traditional method of storing potatoes in clamps over the winter months has stood the test of time but is open to severe criticism from the point of view of wastage. Sound tubers well clamped with good wheat straw, allowed to sweat for some weeks before the final earthing up, will keep well and show sprout growth from one to three inches by March, depending on the variety. Where these conditions are not fulfilled, the danger of wastage is not from frosting but from high temperatures obtaining within the clamp. Early temperature rise due to/

to too early earthing up or to the rotting of diseased tubers brings on sprouting accompanied by increased respiration and a consequent rise in temperature. Crook and Watson (11) found a fairly steady temperature rise in the centre of a clamp from 41 - 68 - 95°F. for the months of November, March and April respectively. In effect, after February when the temperature was at 50°F. the condition of the stored tubers would deteriorate extremely rapidly. As the industry is periodically affected by gluts, this is possibly the reason for the slow development of bulk storage in sheds with temperature control in this country (as opposed to the storage of boxed 'seed' in sheds). The advantages of shed storage include the control of storage temperature and in consequence of sprout growth, coupled with easy handling and independence of adverse weather conditions during "dressing". The disadvantages are the high capital outlay and ventilation costs. Forced ventilation is the only necessary mechanical installation required in sheds in the Netherlands. The temperature of the stacks of potatoes can be held at around 39°F. over the storage period by the use of suitable low temperature air from the outside from time to time. (12) There is no doubt that cool storage at constant temperatures of from 35 - 38°F. is ideal for storage and transport, giving a sound end product with very little sprouting. Samples cooked, subject to controls, showed the quality of tubers from cool storage to be unaffected when boiled. One sample of the variety Majestic after fourteen months in cool storage was boiled along with Majestic tubers from the new crop after two months in clamp storage. The former was judged to be the better quality by nine out of ten randomly requested tasters who had no prior knowledge of the test. Flesh colour is intensified during cool storage and flavour becomes more apparent. In tubers destined for chipping, storage below 40°F. gives a sweet flavour to chips.(13) Very few, if any, growers in this country grow potatoes specifically for the chipping industry but in the United States it is of great commercial importance. Storage above 40°F. is advocated by Smith (13) and can be carried out successfully where sprout inhibitors have been applied in the field. Maleic hydrozide (MH_{40}) is the sprout inhibitor used most commonly in the United States and it gives good control of sprouting where tubers are held at between 45° to 50°F.

The incidence of the spread of rot diseases in cool storage has not been studied specifically but there is evidence that cool-stored tubers are less able to seal-off inoculated material of the gangrene fungi (Phoma foveata Foister and P. tuberosa Melh. Ros. & Sch.) than those tubers stored at a higher temperature, although infection of tubers dipped in a spore suspension was much less at the lower temperature in the presence of moisture.(14) In the tests reported here which covered three seasons the tubers were kept in boxes in a cool store at a constant temperature of 35°F. (± 2) where they remained sound and free from rots.

C. The Effect of Storage on the Subsequent Development of the Potato in the Field.

To observe the after-effects of storage on field performance, two pilot experiments were carried out in 1956 followed by a statistically laid out experiment in 1957 to confirm the results of the pilot experiments.

Pilot Experiments.

1956 A. Tubers from three maincrop varieties, King Edward, Golden Wonder and Arran Consul, from three storage treatments, were planted in nine separate random blocks. The tubers were planted at a double spacing of three feet between plants to obviate the effect of removing plants upon the remainder. Five plants of each variety from each storage condition were harvested at fortnightly intervals after tuberisation and their yields recorded (Table 5).

TABLE/

TABLE 5.

Yields of Fifteen Plant Samples, Five per Variety of Three Maincrop Varieties, King Edward, Golden Wonder and Arran Consul.

Storage Treatment	Weeks from Planting							
	11	13	15	17	19	21	23	25
	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
80°F.	4	17	31	52	59	70	75	81
Air Temperature	$\frac{1}{2}$	8	25	49	66	73	75	80
35°F.	-	3	24	40	57	64	73	73

All the tubers from each sample lift were measured for length, from which the mean tuber length at each lift for the crop from mother tubers from each of the three storage temperatures was obtained. The mean lengths were plotted on a graph to show the relative effect of the storage treatment of the mother tuber on the development of the subsequent crop (Figure 6).

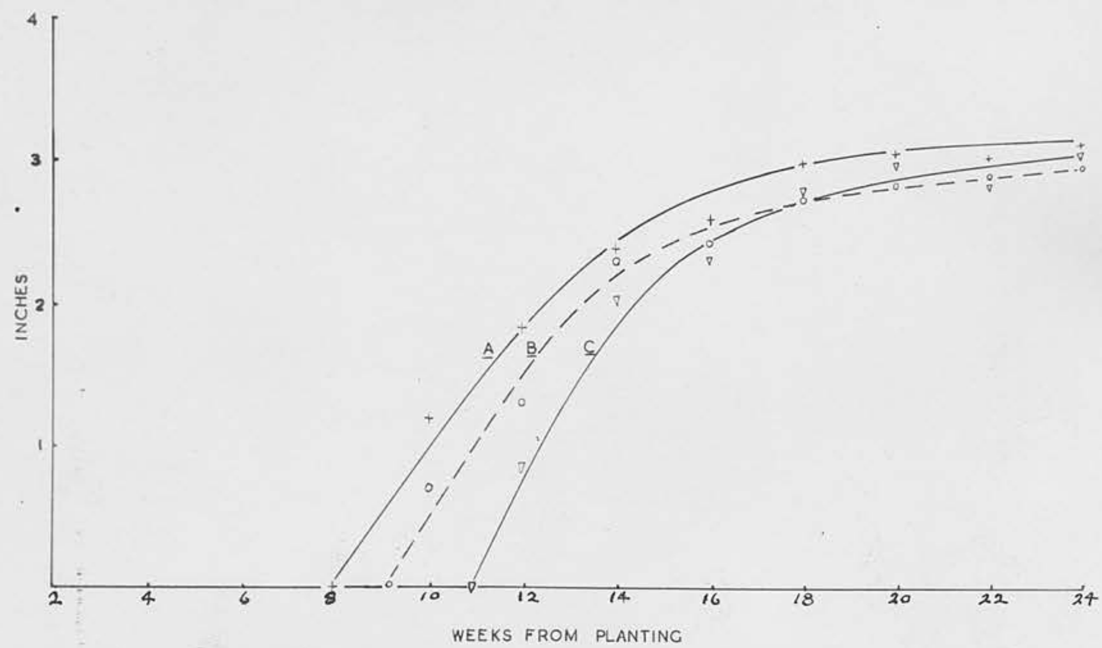

Figure 6. Mean Tuber Size in Inches of Plants of Three Maincrop Varieties, King Edward, Golden Wonder and Arran Consul Grown from Setts Stored at Three Different Temperatures. In the case of Golden Wonder, a long tubered variety, half the sum of the length and breadth was taken. Condition of Storage. A. 80°F. B. Shed. C. 35°F.

<u>1956 B.</u> Plots of five varieties were also planted from tubers stored in the same storage conditions as above and were used for general observation and pilot yield trials (Table 6).

TABLE/

TABLE 6.

Pilot Yield Trial of the Effect of Storage Temperature on Subsequent Maturity and Yield.

Variety		Storage Treatment				
	80°F.		Normal Shed Storage at Concurrent Air Temperatures with heating during frost		35°F.	
	Yield≠	Date of Maturity	Yield≠	Date of Maturity	Yield≠	Date of maturity
	lbs		lbs		lbs	
Arran Pilot 1st Early	69	11/8	84	15/8	96	26/8
Record)Early	57	15/8	83	28/8	89	10/9
Majestic)ly	105	14/9	127	20/9	125	ж
Orion)Main crop	111	18/9	137	ж	126	ж
Kerr's) Pink)Main-crop	112	ж	114	ж	116	ж
Up to) Date)	135	ж	122	ж	123	ж

≠ Yield figures are for 27 tubers planted.

ж Not matured when the haulms were killed by frost 21st September, 1956.

Statistical Experiment.

1957. The most important feature from the above experiments appeared to be the effect of storage on subsequent yield. It will be noted that where growth has been unimpeded by frost, the cooler the storage the higher the yield. A statistical experiment was laid down to substantiate this point in particular and others in general.

An early variety (Epicure) was used for this experiment to ensure that the plants would reahh full maturity in freedom from frost. Ten randomised blocks were planted, each of five plots, one from each storage condition shown below. Each plot was of six tubers planted. The results are shown in Table 7.

TABLE 7.

The Effect of Tuber Storage on Yield (Oz.)

Storage Treatment	Block Number 1	2	3	4	5	6	7	8	9	10	Treatment Total		Treatment Average
Temperature Condition													
80°F. Dry	219	215	168	200	235	232	256	230	166	167	2,088		208.8
80°F. High Humidity	222	120	148	99	242	176	187	142	194	160	1,690		169.0
80°F. Do. plus Light Access	168	276	223	252	244	193	203	164	154	185	2,062		206.2
Concurrent Air Temperatures above Freezing Point	241	275	361	386	342	278	331	320	284	310	3,128		312.8
35°F.	330	326	371	350	336	368	322	350	419	347	3,519		351.9
Block Totals	1,180	1,212	1,271	1,287	1,399	1,247	1299	1,206	1,217	1,169	12,487	Mean Significant Difference	49.3 (1%) 36.7 (5%)

The above result (Table 7) shows conclusively that the conditions of storage of the planted sett affects the subsequent yield. The cooler the storage the higher is the yield. Tubers stored at 80°F. give a lower yield at the 1% level of significance than those stored at lower temperatures. Storage of tubers at 80°F. in highly humid conditions gives a lower yield at the 5% level of significance than those stored at the same temperature and conditions but having access to light, and than those at the same temperature but in dry conditions. More important for practical purposes, tubers stored in cold conditions outyield normal shed-stored tubers, the result being significant at the 5% level.

Discussion on the Effect of Storage on the Subsequent Development of the Potato in the Field.

From the results shown above and from observations made in the field, it is possible to form a picture of the after-effects of storage. Plants from tubers stored at 80°F. emerged on the average fourteen days before these tubers which were shed stored at concurrent air temperatures above freezing point. The latter emerged about eight days before those stored at 35°F. This difference in vigour was obvious between the three treatments until almost mid season eleven weeks after planting. This superior vigour early in the season can only be attributed to the size and robust appearance of the sprouts on the tubers from warm storage as compared with the others at the time of planting (Appendix 4). From Figure 6 it will be observed that for maincrop varieties tuberisation begins on the eighth, ninth and eleventh week after planting for warm, shed and cool stored tubers respectively. Although cool stored tubers are later to commence tuberisation, the growth of the tubers is more rapid and they eventually outyield the tubers from the other warmer storage conditions when unimpeded by frost in the later stages of growth (Tables 6 and 7). This later vigour of the cool stored tubers can conceivably be attributable to the condition of the tubers at planting time. The cooler the storage the sounder is the tuber and the less there is of sprout growth. From this it may be deduced that the loss from the reserve food material in the tuber is at a minimum at planting time. In early varieties or where the maturing haulm is unaffected by frost the warmer the storage the earlier is the maturity. The term "haulm maturity" is used here as meaning the first point in time at which maximum yield is obtained, and is judged by the yellowing of the senescent haulm.

Where earliness of cropping is the commercial factor of prime importance to potato growers for the "Early" market, fairly warm storage (45 - 50°F.) of 'seed' tubers with a good light access would appear to be a good method of promoting an earlier crop.

D. A Physiological Condition which Occurs Occasionally in the Field and is in part Attributable to Warm Storage.

A feature of the effect of warm storage is the incidence of "little potato", a physiological condition where the life cycle is contracted as evidenced by the production of young tubers on the sprouts of the old 'sett' (Appendix 9b). During the field experiments reported in sub-section C all the tubers from storage at 80°F. showed stout unbranched sprouts and produced normal plants (Appendix 4c). From one lot of the variety Dr. McIntosh a few tubers were noticed showing an extreme form of sprout proliferation which appeared to have been due to damage to the apices of the original sprouts (Appendix 9a). These tubers all produced the condition of "little potato" when planted in the field (Appendix 9b). The conditions in the field were adverse for growth during the first fourteen days after planting.

Previous Literature. Van Schreven (15) found that the loss of reserve food material during three months storage at 68°F. prior to planting, produced thirty-three percent of the condition "little potato" when the controlled growing conditions after planting were cold. When he used the same storage and growing conditions but with desprouting of the tubers before planting, one hundred per cent "little potato" was obtained. Storage at 50°F., coupled with desprouting before planting in good growing conditions, produced thirty-three per cent "little potato". The latter was from small mother tubers only.

Experimental Work. To investigate the findings of van Schreven and the observations of the Dr. McIntosh tubers mentioned above, the following series of experiments were carried out.

i. It was found that symptoms of "little Potato" could be produced artificially by transferring sprouted tubers from warm to cold storage. A typical tuber from this treatment is shown in Appendix 10.

ii. Three lots of Majestic tubers in storage at 80°F. and in other storage conditions (Table 8) had sprouts of approximately one inch in length in February. The sprouts were cut across at the apices to induce some degree of proliferation. Four tubers from each storage condition were planted in pots in a soil and compost mixture in April and allowed to grow in the range of temperatures shown below. Ten tubers from each storage condition were also planted in the field at the same time. The percentage of plants which showed the condition of "little potato" when harvested later in the season is given in Table 8.

TABLE/

TABLE 8.

The Amount of "Little Potato" Condition Produced, Shown as a Percentage, from Tubers with Proliferated Sprouts Grown in Four Different Conditions.

Storage Conditions Temp.	Approx. R.H.	Dark or Light	Greenhouse (Approximate Temperatures °F. 65-75)	Cool Shed (40-50)	Field (35-45)	Cool Store (39 (±2))
80°F.	40%	Dark	0	0	50 (20)≠	100
80°F.	95%	Dark	0	0	50 (40)	100
80°F.	95%	Light	0	0	30 (10)	100

≠ Figures in brackets denote percentage of plants which failed to grow at all.

iii. Normally sprouted tubers of the variety Majestic which had been in five different storage treatments were used in the following experiment. Eight tubers from each storage treatment were used for each growing condition, four of which were desprouted and all were planted in pots and were grown in three different growing conditions in April. Ten sprouted and ten desprouted from each storage condition were grown in the field at the same time (Table 9).

TABLE/

TABLE 9.

The Amount of "Little Potato" Condition Produced, Shown as a Percentage, from Tubers with Normal Sprouts and with Sprouts Removed when Grown in Four Different Conditions.

Growing Conditions / Approximate Temperature °F.			Sprouted				Desprouted			
			Green-house 65-75	Cool Shed 40-50	Field 35-45	Cool Store 39(±2)	Green-house 65-75	Cool Shed 40-50	Field 35-45	Cool Store 39(±2)
Storage Conditions Temp.	Approx. R.H.	Dark or Light								
80°F.	40%	Dark	0	0	0	50	0	25	20(80)	0(100)
80°F.	95%	Dark	0	0	0	50	0	25(25)≠	0(100)	0(100)
80°F.	95%	Light	0	0	0	25	0	0	10(90)	25(75)
Shed Storage at Concurrent Air Temperatures above F.P.			0	0	0	0	0	0	0	0
35°F.	-	Dark	0	0	0	0	0[x]	0[x]	0[x]	0[x]

≠ Figures in brackets denote percentage of plants which failed to grow.

x Tubers from storage at 35°F. had very short sprouts when desprouted.

It may be observed from the above results that the condition of "little potato" was produced on tubers from warm storage only. Tubers with proliferated sprouts showed after planting more "little potato" than those with normal sprouts. All the desprouted tubers from warm storage either failed to grow or produced "little potato" when planted in the field or in pots in cold growing conditions. Tubers from warm storage with access to light showed a lesser tendency to produce "little potato" than those stored in the dark. Shed stored and cool stored tubers even when desprouted before planting showed no tendency to produce "little potato".

Discussion.

It would appear that one of the factors in causing "little potato" is over-warm storage. The latter might be defined as any condition of temperature and available light which produces emaciation of the tuber to some degree at the end of the normal storage period.

Another factor is the type of sprouting. Emaciated tubers from warm storage with single or double sprouts grew normally when planted except in very cool growing conditions where some "little potato" was produced (Table 9). Tubers from the same storage but having to some degree of sprout proliferation when planted in cool growing conditions, showed eventually one hundred per cent "little potato" and sixty-six per cent (including failure to grow) after planting in the field (Table 8).

Desprouting increased the incidence of "little potato" and also of complete failure to grow

(Table 9).

The last factor of the cause of "little potato" is cool growing conditions immediately after planting.

In over-warm conditions of storage tubers lose a great deal of reserve food material due to above normal respiration and to sprout production. They eventually become emaciated and rubbery. Where there are only one or two robust sprouts per tuber to be nurtured, growth on planting is normal except where the conditions are very cold and some "little potato" results. Where desprouting of such tubers is carried out before planting, the initiation of new growth in fair to poor growing conditions proves too great a task and the tubers either fail to grow entirely or they produce "little potato". In the same way, when tubers from warm storage are faced with the task of supplying numerous growing points as in the case of proliferated sprouting, "little potato" or complete absence of growth results in fair to poor growing conditions. These findings corroborate those of van Schreven mentioned above.

In commercial practice the complete failure of a potato crop is occasionally experienced due to "little potato" and to absence of growth from the setts. It is to be noted, however, that the most general cause of blankings in potato crops is due to fungal infection of the setts. In this country the commonest causal agent of blanking being the fungus disease "skin spot" (Oospora pustulans Owen & Wakef.). With regard to crop failure from "little potato" no detailed information is usually available about the conditions of storage of the mother tubers. No doubt heating in the clamps associated with excessive sprout growth, followed by desprouting during dressing and planting in cool growing conditions are among the contributory factors.

Conclusions. (Part I)

1. Sprout growth is continuous at the apical eye of potato tubers after harvest. There is no incapacity for growth, but this growth is not visible to the naked eye as a sprout for a period of time depending on the condition of storage.

2. Temperature is the primary factor in controlling the length of the period from harvest to the point of minimal visible sprouting; humidity may have some effect in the lower temperature range but light has no effect.

3. After minimal visible sprouting takes place, temperature and light play compensating roles in the control of sprout growth for the remainder of the storage period. Light access is the more important factor in the range of temperature from 45 - 65°F.

4. Of the factors other than physical which affect

the/

the length of the period from harvest to minimal visible sprouting and the subsequent sprout development in healthy tubers, varietal differences are found to be the most important.

5. Cool storage at 35 - 40°F. is ideal from the point of view of the soundness of the end product with a minimum of sprout growth.

6. The warmer the storage condition of the sett tubers the earlier is tuberisation and maturity in the field, but the lower is the final yield compared with cooler-stored sett tubers of the same variety.

7. A critical point is reached in the life cycle of the potato plant when, through loss of reserve food material from the tuber in storage and when planted in adverse conditions for growth, perennation is accomplished by the formation of fresh tubers direct from the mother sett. The condition is called "little potato". Other contributory factors are desprouting of the tuber or the type of sprout growth at planting. In extreme cases no growth of any kind takes place and the sett dies.

PART II.

TUBER AND YIELD DEVELOPMENT IN THE FIELD.

INTRODUCTION.

Little is known of the normal development of the potato crop in the field, the stages of growth during this period, and the relationship between stem and tuber. In order to elucidate some of these points the following experiments were carried out:-

1. a. To find the point of tuberisation and of maximum crop increase and to analyse the crop development in relation to individual tubers.

   b. To obtain a pattern of yield development in relation to the growing period in the field.

   c. To find the relationship of tuber to stem with regard to relative tuber size.

2. To ascertain if the amount of the flow of reserve food material into a growing tuber is in direct proportion to its mass.

Experiment 1.

Previous Literature. The experimental procedure detailed below is based on similar work carried out by Krijthe.(16) Some differences in technique were used here. Krijthe used individual varieties; here three varieties from three different storage conditions were combined in the experiment. Also Krijthe used normal field spacing between plants and irregular sampling, here the spacing was 3 ft. x 3 ft. with regular sampling. The effect of the differences in technique will be discussed later.

<u>Method</u>. Three varieties of potatoes, Golden Wonder, King Edward and Arran Consul, each from three different storage conditions, were planted in the field in nine separate random blocks. The individual tubers were planted at three feet intervals in each direction to avoid interference to the roots and to the amount of available light when neighbouring plants were removed during the growing season. Five plants from each variety and treatment were lifted at two-weekly intervals throughout the growing season after tuber formation was first apparent. All the tubers from each lift were measured and the length of each tuber was taken as a convenient equivalent of weight. In the case of Golden Wonder, a long variety, the length and breadth of each tuber was measured and half the sum was taken as being a more accurate reading than that of length alone. In view of the large number of tubers to be measured accurately, a piece of equipment was designed and constructed in order to facilitate the taking of the readings (Appendix 11).

<u>Results</u>.

<u>a</u>. From the nine individual bi-weekly sample lifts it was possible to obtain a mean length for the first, tenth, twentieth, fortieth and sixtieth tuber in

descending order of size throughout the period of crop development. Any possible individual effect due to the variety or the previous storage condition of the mother sett was ruled out by the technique used and an accurate analysis of crop development in relation to the tuber population was obtained (Figure 7).

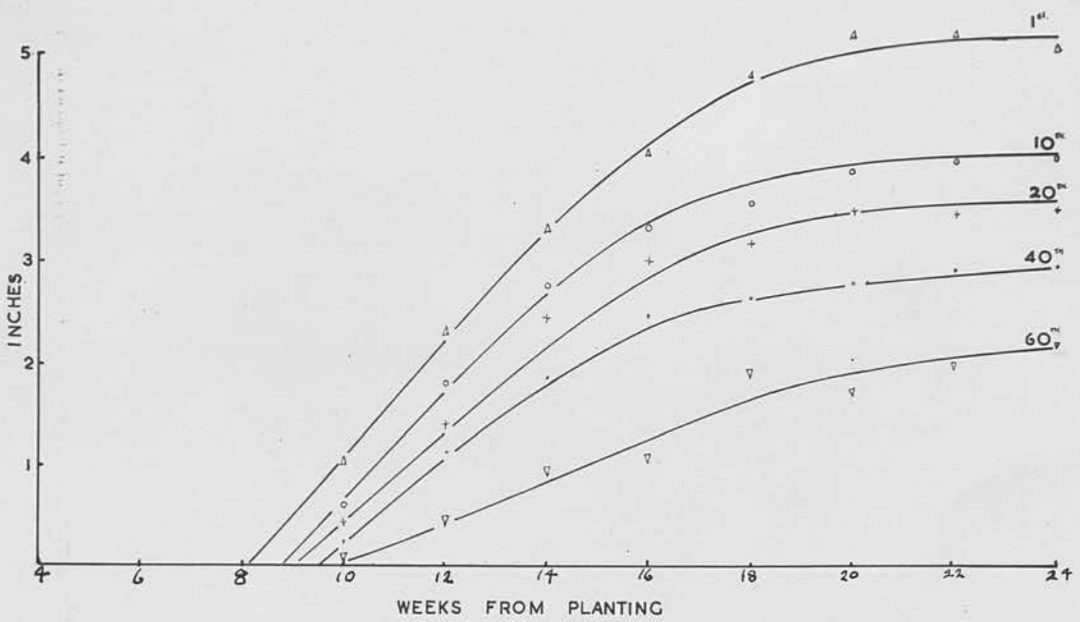

Figure 7. The Mean Length of the First, Tenth, Twentieth, Fortieth and Sixtieth Tubers for Samples of Five Plants from Nine Separate Lifts Comprising Three Maincrop Varieties and Three Different Storage Conditions of the Setts, Harvested at Bi-Weekly Intervals.

The plots were planted on the 18th of April and it was in the ninth or tenth week before tuberisation took place, a third of the way through the growing season. The first sample lift was taken on the 30th of June ten weeks after planting. Tuber growth is rapid for eight weeks after tuberisation until the end of August, this is followed by little apparent tuber increase although, as may be seen from Figure 8, only 76 per cent of the total yield has been reached.

Discussion.

a. The point of tuberisation in late varieties occurs one-third of the way through the growing season. This was later in the growing season than was first anticipated. Krijthe,(16) using similar methods to those already described, found that a recession of growth occurred two or three weeks before maturity. This anomaly was accounted for by growing conditions in the Netherlands, but it would appear to be due to the methods of planting and sampling used. After two or three initial samples had been taken at weekly intervals from a plot, it was left for three or four weeks during the period of maximum crop increase and sampled again. The latter was, in nearly all of the cases cited, a high reading as compared with the next sample taken a week later. The planting had been carried out at normal spacing (in the Netherlands possibly 15 x 26 inches) and the samples were drawn by paring along the drills from the outsides of the plots. This meant that the sample row left for three or four weeks had an advantage over the sample row to be lifted a week later as it was exposed to extra light during this period. Also the former sample row had three or four weeks in which to recover from root damage as against one week fob the latter, which, in consequence, gave the lower reading. Smooth diverging curves resulted in the experiment reported here, by wide spacing between plants and regular sampling. On the assumption, which will be shown later to be correct, that, in general, the largest tuber remains the largest and the smallest the smallest, it can be stated that the larger the tuber the faster it grows, as can be seen by the divergence of the curves in Figure 7.

Results.

b. To obtain an assessment of yield development during the growing season, the weights of each lift, in all forty-five plants per lift, were taken and plotted on a graph (Figure 8).

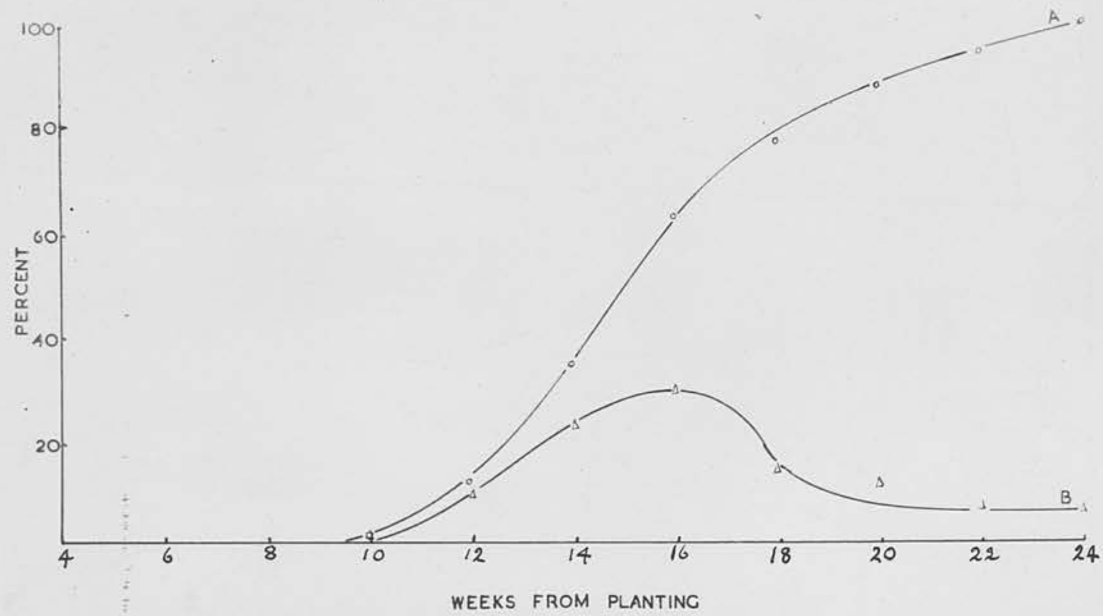

Figure 8. The Development of Yield in the Potato Plant (Maincrop Varieties).

Curve A. Percentage of Total Yield.

Curve B. Percentage Increase in Yield.

Discussion.

b. The period of maximum crop increase occurred between the eleventh and the twenty-fifth of August, during the 14th - 16th week after planting and 6 - 8 weeks after tuberisation. Half the total yield was produced within four weeks from the 28th July to the 25th of August between the twelfth to the sixteenth week after planting.

The growing season of the potato plant (main-crop varieties) may be divided into three stages of eight weeks each.

i Vegetative growth; ii Tuberisation and rapid tuber development, and iii Gradual senescence of the haulm accompanied by the abrupt slowing of tuber development.

Observations and Discussion.

c. (The Relationship of Tuber to Stem). In the experiment the average number of tubers per plant at tuberisation was found to agree almost exactly with the number per plant at the final mature lifts. It was in fact fairly constant throughout the trial. There was a slight varietal difference. Arran Consul averaged thirteen, Golden Wonder fourteen, and King Edward eighteen tubers which finally were of economic value, each with four or five tubers finally below one inch in length. With the varieties "Bintje", "Eigenhiemer" and "Voran", Krijthe[16] found that only sixteen to twenty out of thirty-five to fifty tubers formed at tuberisation, reached economic size. In the experiment reported here there was no such wastage.

On examination, the position of the tubers in relation to the stem was found to be in some degree correlated to the relative tuber size. It was found that the largest was produced one-third of the distance and the second largest two-thirds of the distance from the sett to ground level. The third largest was usually below and nearer the sett than the largest and the fourth largest on branch stolons. This order is in general agreement with the finding of Krijthe.[16]

From the measurements carried out in connection with this experiment, an average plant was found to have about fourteen tubers of economic size at maturity. This number is in the main independent of the number of stems or branch stems. The tubers per plant on the average show two large, four medium large, four medium small, four small, with four smaller tubers below economic size. A diagram of the average potato plant has been constructed (Figure 9).

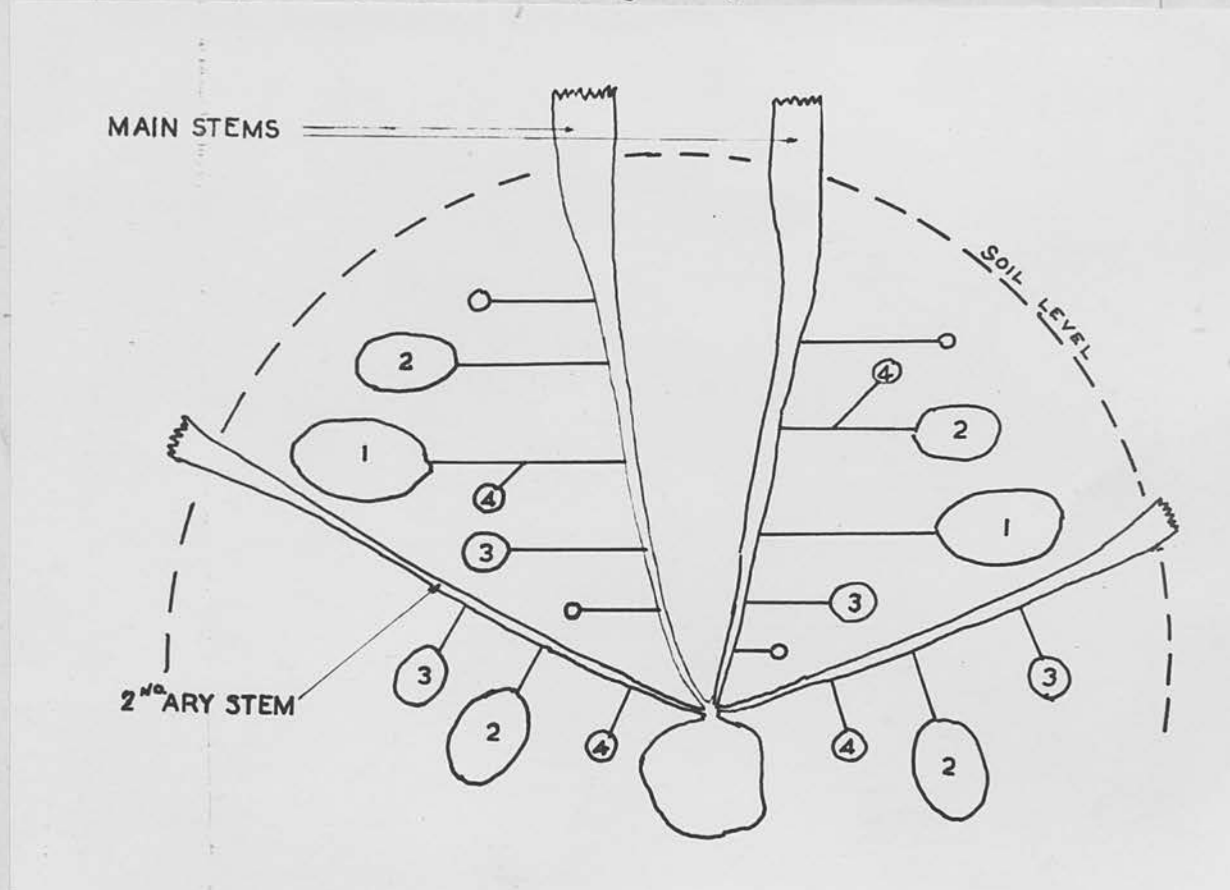

Figure 9. The Relationship of Tuber to Stem with regard to the Relative Tuber Size in the Potato Plant. Tubers of Economic Value are scored in Order of Size.

Experiment 2.

To ascertain whether the flow of storage products into the tubers from the stem and leaves is in direct proportion to their mass, the following experiment was carried out.

Method. Eight scooped out, single eyes from each of three varieties, Epicure, Redskin and Great Scot, were planted at the surface of half filled 12 inch pots. Over each 'sett' was placed an open ended 5 x 5 inch hollow can which was filled with compost soil mixture to form a core above the 'sett'. The plants were allowed to grow until the single stem appeared through the core. The can was then removed leaving a soil core intact round the stem. Light was excluded by a pot cover from the developing young tubers, which appeared eventually at the edges of the core. The humidity of the greenhouse was kept as high as possible. Each tuber was tallied as it appeared and the increases in length noted from week to week.

Result. The average of tubers produced per stem was four: of these one, two or three were present at the first examination date, the others being present the following week or, in some cases, the next again. It was only feasible to compare the growth of the first and second largest at the first examination and the first and second largest at harvest. It was found that ninety-four per cent of the largest first formed tubers were the largest at harvest and the remainder were second largest and eighty-eight per cent of the second largest first formed tubers were the largest or second largest at harvest.

The mean growth curves for these are shown in Figure 10.

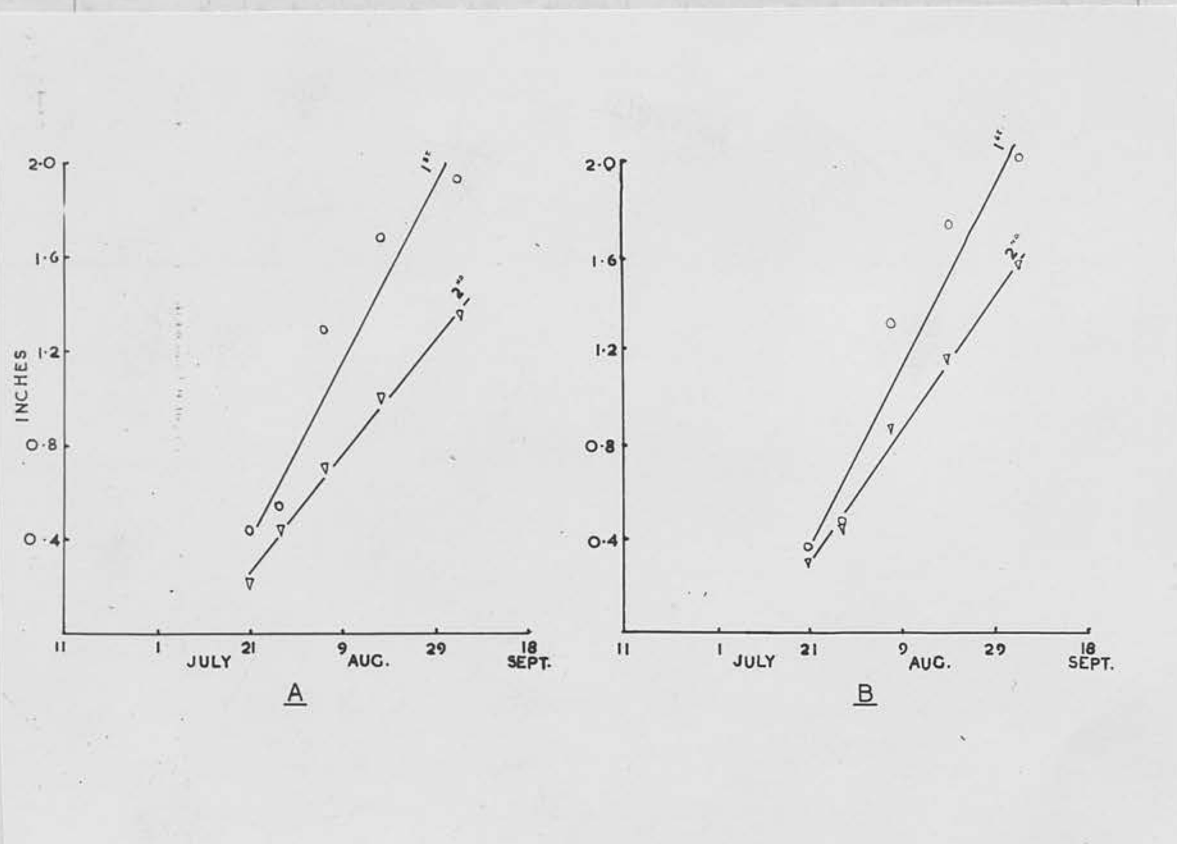

Figure 10. The Mean Tuber Increase in Length for Twenty-four Single Stemmed Potato Plants of Three Different Varieties in Pots.

Graph A. 1st. Path of Increase of Largest tuber at Tuberisation.
2nd. Path of Increase of Second Largest Tuber at Tuberisation.

Graph B. 1st. Path of Increase of Largest Tuber at Harvest.
2nd. Path of Increase of Second Largest Tuber at Harvest.

Discussion. From Figure 10 it may be deduced that the larger the tuber the faster it grows. Graph B shows the influence of the six per cent of the second largest at tuberisation being largest at harvest and of the six per cent largest at tuberisation being second largest at harvest, the latter curve being steepened also by one or two later starters being second largest at harvest.

One feature of the experiment was that the initial development of all the tubers took place within the core of soil on very short stolons and as development proceeded, they swelled into the surrounding air space. The reason for this might be that the lower humidity of the air space surrounding the core and of the outer layer of the core itself restricted the growth in length of the developing stolons and brought about tuberisation on much shorter stolons than is normally the case in the field.

Conclusions on Tuber and Yield Development in the Field.

1. Tuber formation in maincrop varieties takes place between the 8th and 10th week after planting.

2. Maximum crop increase in maincrop varieties occurs between the 12th and 16th week after planting and approximately three weeks after tuber formation.

3. Increase in size of a tuber is rapid in the early stages but appears to be evenly continuous till maturity.

4. The growing season of maincrop varieties of potatoes may be divided into three stages of eight weeks each; (a) vegetative growth; (b) tuberisation and rapid tuber (and yield) development, and (c) senescence accompanied by the abrupt slowing down of the rate of tuber growth.

5. Potato plants in normal growing conditions produce on the average fourteen tubers of economic size, with four or five below one inch in length. The former is composed of two large, four medium large, four medium small, and four small. This is in the main independent of the number of stems. For a greater number of stems than four, the number of tubers increases and the relative size falls; for a lesser number of stems than four, the reverse is the case.

6. Assuming that tuber weight increase is equivalent to the total intake of reserve food material over the same period of time, then it may be stated that the amount of the flow of reserve food material into a tuber is in direct proportion to its mass.

PART III.

THE STABILITY OF POTATO CLONES WITH REGARD TO YIELD.

INTRODUCTION.

With the wide use of disease-free, high-yielding clones of potatoes for the building up of 'seed' stocks, some knowledge of their stability with regard to yield is of great importance. Also if changes in yield occur within clones, some indication of the amount of change to be expected over the years deserves investigation.

Previous Literature.

The first variants observed in potato varieties were chimerical in nature and were those which were distinct from the normal by colour differences in the Tuber. Of such origin was the variety 'Golden Wonder' introduced in 1906.(17) It is a russet tubered variant of the variety 'Maincrop' which was bred in 1876. In the 1920's when certification of 'seed' stocks was under way in Scotland, variants of later maturity than, and having some foliar differences from, the normal were observed. These variants were found in almost all of the earlier maturing varieties and were called 'Bolters' and 'Semi-bolters'.(18) Other foliar variants were also observed at this time, differing fairly obviously from the normal and in many cases having a lower yield,[18] i.e. "wildings" and "undesirable variations".

In Australia it was found in 1950[19] that in some varieties early and later maturing clones could be selected which showed no foliar differences from the normal. Although more concerned with maturity variants, Bald found clones which were capable in certain areas of consistently outcropping other clones of similar maturity.

Clone testing has been carried out in Holland since 1950 to prevent the progeny of low yielding clones reaching the open market. All clone raising is supervised by the Netherlands Inspection Service, the clones being tested in small plots in very uniform fields at different centres over a period of from three to five years.[20] The author, with the co-operation of D. N. Lawley,* carried out an extensive trial from 1950 to 1955, in which concrete evidence of clonal variation affecting yield was established in 1953[21] and again confirmed in 1954 and 1955.

Clonal variation affecting yield in the potato was also substantiated by Cockerham and McArthur in 1956.[22]

It is evident that if clones arise which are variants of the normal with regard to yield of varieties originating from true seed, it may be assumed that these clones/

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* Mathematics Department, Edinburgh University.

clones will also from time to time give rise to clones which differ in yield from the clonal mean to such an extent that they may be identified as new variants.

An experiment was undertaken with a view to establishing if possible the stability of potato clones with regard to yield.

Methods and Materials. In order to observe changes within clones it was necessary to have a clonal line of some years standing. For this purpose the original clone 'A' of the author's 1950 to 1955 series of trials was selected. It was the consistent highest-yielding clone, being second highest in 1953 and highest in 1954 and 1955. It was possible to use this material in this further trial due to the fact that the original variety was particularly suitable from the point of view of continued freedom from aphid borne disease. The variety King Edward is field-immune from viruses 'X', 'A' and 'C'. The health of the stock was as good at the finish of the trials as at the start. No aphid borne infection of virus 'Y' or leaf-roll appeared. For tests to be carried out over a number of years it has been found that in using initially virus 'X'-free tested material of varieties susceptible to virus 'X', infiltration of viruses, and of virus 'X' in particular, have lowered the accuracy of the results to some extent. This may be observed from the results of Cockerham and McArthur (22) where virus 'X'-tested material of the

variety/

variety Majestic was used. At the end of the four years trial, 50 per cent mild mosaic ('X') was present along with 3 per cent virus 'Y' and 6.6 per cent leaf-roll.

The variety King Edward is a symptomless carrier of an individual strain of virus 'S' called 'Para-crinkle', every plant of the variety being infected.[(23)] This is a mild virus in King Edward and appears to be exceptionally stable. The presence of this virus is not thought to have affected the results as any slight effect it may have on yield would be general to all plants of the variety.

In order to avoid infection with blight (<u>Phytophthora infestans</u>), the plots were hand sprayed twice during the growing seasons and were free from blight. They were lifted after the haulms were mature.

One hundred tubers, randomly selected from the graded produce of the original clone 'A' from the previous year's trial, were planted in a block in 1955. All plants were lifted at maturity, weighed individually, and from these plants (each a clone) eight were selected to give a maximum range from the highest to the lowest yielder. Six setts from each of the new clones were planted in six randomised blocks in 1956, and in 1957, thirty-six setts randomly chosen from the bulk produce of each 1956 clone, were planted in thirty-six randomised blocks. All the individual sett weights and yields/

yields were recorded. The spacing between plants was eighteen inches and between drills was twenty-eight inches. Tubers, surplus to requirements, were planted round the plot to eliminate "end" effect. The planting plan for the final year is shown below.

<u>Planting Plan of Clone Trial, 1957.</u>

Block No.	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
	(B	F	D	E	C	C	H	C	B	A	F	H	O	O	H	O	F	B
Half	(C	O	E	C	A	O	F	F	O	E	A	O	F	E	D	C	H	H
Drills	(H	E	C	O	O	E	E	O	E	O	O	F	C	F	F	E	D	A
	(D	D	A	A	H	H	B	E	A	H	H	E	H	H	A	F	C	D
a.	(O	B	H	H	E	A	A	D	F	D	E	C	B	C	B	D	B	F
	(F	C	O	D	F	F	O	H	D	F	D	D	E	B	E	H	A	E
	(A	H	F	F	B	D	C	A	C	C	B	B	D	D	O	A	O	O
	(E	A	B	B	D	B	D	B	H	B	C	A	A	A	C	B	E	C

Block No.	19	20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36
	(D	C	H	O	D	C	C	H	O	F	E	E	B	E	E	E	H	F
Half	(E	F	F	F	B	A	H	C	F	B	O	F	H	O	C	H	A	C
Drills	(F	D	E	E	H	D	D	A	B	D	B	H	C	C	B	F	B	O
	(C	A	C	C	O	E	F	F	A	E	A	O	F	F	O	O	F	E
b.	(A	H	D	B	C	B	O	E	D	C	D	A	E	H	D	C	O	B
	(B	O	O	H	A	F	A	O	E	A	F	C	O	D	H	D	D	H
	(O	E	A	A	E	O	B	D	C	H	C	D	A	A	A	B	C	D
	(H	B	B	D	F	H	E	B	H	O	H	B	D	B	F	A	E	A

<u>Results</u>. 1955. Eight clones, selected from a hundred tuber plot of the original clone 'A', in order of weight of total yield

	lbs.	oz.		lbs.	oz.
E	3	2	H	2	0
F	2	12	D	1	15
B	2	11	A	1	11
C	2	5	O	-	11

No clones were found with yield weights between the lowest (11 oz.) and 1 lb. 11 oz.

1956./

1956. Six randomised blocks were planted, having one tuber from each clone. The sett weights and yields were recorded but there was too little material to carry out an analysis. The mean yields are given in order of weight.

	lbs.	oz.		lbs.	oz.
D	3	12	F	2	15
E	3	6	H	2	15
C	3	1	B	2	14
A	3	0	O	2	4

1957. Thirty six randomised blocks were planted, each block having one tuber from each clone. The sett weights and yields are shown below.

<u>Clones</u>./

CLONES

Block No.	A Sett Weight ¼ ozs.	A Yield ozs.	B Sett Weight ¼ ozs.	B Yield ozs.	C Sett Weight ¼ ozs.	C Yield ozs.	D Sett Weight ¼ ozs.	D Yield ozs.	E Sett Weight ¼ ozs.	E Yield ozs.	F Sett Weight ¼ ozs.	F Yield ozs.	G Sett Weight ¼ ozs.	G Yield ozs.	H Sett Weight ¼ ozs.	H Yield ozs.	Block Totals Sett Weight ¼ ozs.	Block Totals Yield ozs.
1	7	32	16	28	32	41	15	35	10	35	25	50	14	49	20	63	139	333
2	9	32	6	24	15	41	13	29	14	35	9	28	29	38	6	28	101	255
3	29	42	6	26	20	46	16	55	7	37	8	42	20	35	15	36	121	319
4	32	58	19	40	24	54	21	54	25	53	15	40	11	26	24	40	171	365
5	28	66	7	30	11	35	14	38	29	46	13	47	23	50	20	50	145	362
6	13	45	13	45	6	36	6	33	24	39	27	47	11	41	18	52	118	338
7	13	50	21	51	16	41	23	69	10	42	8	36	15	33	28	69	134	391
8	15	81	7	28	20	73	14	44	11	41	18	36	8	42	9	34	102	379
9	48	56	11	47	21	63	17	67	26	52	10	45	12	38	22	50	167	418
10	6	32	7	36	11	51	21	57	33	44	14	32	11	35	26	42	129	329
11	22	42	46	42	18	42	14	46	20	40	14	39	6	19	8	33	148	303
12	10	37	26	42	17	56	19	36	20	52	8	39	20	59	12	48	132	369
13	27	57	28	66	10	43	17	28	19	37	38	52	6	26	8	33	153	342
14	34	49	10	29	18	46	5	20	14	48	16	40	8	32	21	39	126	303
15	24	20	23	66	7	57	7	29	7	39	24	38	29	44	10	43	131	336
16	20	60	22	39	18	53	5	5	7	26	18	63	14	41	23	65	127	352
17	9	41	25	67	12	39	18	54	12	38	10	42	7	32	6	31	99	344
18	9	38	35	56	12	69	18	78	14	62	17	50	7	21	14	32	126	406
19	14	31	8	33	20	54	33	54	20	35	18	50	20	38	26	57	159	352
20	12	28	32	66	15	45	18	51	8	29	20	39	50	65	5	33	160	356
21	10	29	23	40	6	23	14	24	32	53	37	41	9	28	38	52	169	290
22	4	24	35	43	22	37	33	75	25	58	6	39	26	61	20	51	171	388
23	25	45	22	33	5	28	14	39	12	41	17	58	20	45	22	49	137	338
24	22	37	13	32	19	54	32	48	31	68	10	19	9	43	6	48	142	349
25	10	24	17	46	12	28	12	56	11	51	16	42	9	14	39	68	126	329
26	14	61	6	39	17	39	23	60	19	45	23	58	50	62	22	34	174	398
27	7	36	19	39	15	42	16	52	12	42	12	35	14	32	20	62	115	340
28	13	46	9	33	20	37	28	51	11	37	28	47	39	57	10	37	158	345
29	23	34	13	36	11	44	11	44	12	38	20	48	11	25	16	66	117	335
30	31	64	6	40	6	32	36	64	14	39	24	46	16	27	22	51	155	363
31	9	30	14	34	13	54	34	67	33	58	12	30	14	33	12	29	141	335
32	21	72	14	36	21	46	11	42	10	33	6	35	35	42	7	39	125	345
33	11	24	8	43	11	40	17	42	8	34	15	34	9	33	24	63	103	313
34	8	34	14	54	24	59	18	48	36	63	12	54	18	40	18	38	148	390
35	9	30	13	34	31	78	16	66	12	42	12	23	14	30	26	71	133	374
36	11	45	28	60	9	38	24	49	28	54	11	44	22	44	7	29	140	363
Clone Totals	609	1,532	622	1,503	565	1,664	653	1,709	636	1,586	591	1,508	636	1,380	630	1,665	4,942	12,547

Note. Half drills a = blocks 1 - 18.
Do. do. b = do. 19 - 36.

Statistical Analysis of the Results and Discussion.

Analysis of Variance of 'y' (yield) neglecting Sett Weight.

		d.f.	S.sq.	Mean Sq.	Variance Ratio
Between half drills	(a and b	1	12.087	12.087	-
	(remainder	34	4859.913	142.913	-
Between clones		7	2313.531	330.531	2.013 (N.S.)
Error		245	40223.179	164.179	
Total		287	47408.747		

As indicated by the analysis of variance above, there are no significant differences when the yield alone is analysed.

Analysis of Variance of 'x' (sett weight)

		d.f.	S.Sq.	Mean Sq.	Variance Ratio
Between half drills	(a and b	1	144.5	144.5	1.7 (N.S.)
	(remainder	34	1777.403	52.277	-
Between clones		7	156.986	22.427	-
Error		245	20833.764	85.035	
Total		287	22912.653		

As indicated by the analysis of variance of 'x' there are no significant differences in the sett weights.

Sum of Squares of Products (xy).

		d.f.	S.Sq.
Between half drills	(a and b	1	41.791
	(remainder	34	1095.674
Between clones		7	-10.118
Error		245	17972.618
Total		287	19099.965

Elimination of Sett Weight 'x' (S.Sq.)

1. Clones.

d.f.		$S(x^2)$	$S(xy)$	$S(y^2)$	$\frac{(xy)^2}{(x)^2}$	$(yx)^2$	(d.f.)
7	Clones	156.986	-10.118	2,313.719		2,446.989	(7)
245	Error	20,833.764	17,972.965	40,223.906	15,504.992	24,718.914	(244)
252	Clones +Error	20,990.750	17,962.847	42,537.625	15,371.722	27,165.903	(251)

11. a v. b (half drills)

d.f.		$S(x^2)$	$S(xy)$	$S(y^2)$	$\frac{(xy)^2}{(x)^2}$	$(yx)^2$	(d.f.)
1	a v. b	144.5	41.791	12.087		47.189	(1)
245	Error	20,833.764	17,972.965	40,223.906	15,504.992	24,718.914	(244)
246	Error +a v. b	20,978.264	18,014.756	40,235.993	15,469.890	24,766.103	(245)

111. Remainder (half drills)

d.f.		$S(x^2)$	$S(xy)$	$S(y^2)$	$\frac{(xy)^2}{(x)^2}$	$(yx)^2$	(d.f.)
34	Remainder	1,777.403	1,095.674	4,859.035		4,282.902	(34)
245	Error	20,833.764	17,972.965	40,223.906	15,504.992	24,718.914	(244)
279	Error +Remainder	22,611.167	19,068.639	45,082.941	16,081.125	29,001.816	(278)

Analysis of Variance of Yield with the Elimination of Sett Weight.

		d.f.	S.Sq.	Mean Sq.	Variance Ratio	
Between	(a v. b	1	47.189	47.189	0.466	(N.S.)
half drills	(Remainder	34	4,282.902	125.968	1.24	(N.S.)
	Clones	7	2,446.989	349.570	3.45	(1% Sig.)
	Error	244	24,718.914	101.306		
		286				

From the analysis of variance above, after the elimination of the influence of sett weight, there are highly significant differences between clones as regards yield at 1 per cent level of significance. An increase of 1 oz. in the sett weight was found to give an average increase of 3.45 oz. in yield, i.e. the regression coefficient was 3.45 ($\pm$ 0.28).

Corrected Mean Yields. If for any clone '$\bar{x}$' and '$\bar{y}$' are the means of the total sett weight 'x' and the total yield 'y', the mean yield corrected for a mean sett weight of 4 oz. is $\bar{y} + C(4 - \bar{x})$ where C = regression coefficient.

Mean Yields (Oz.) per Sett.

Clone	Uncorrected Yield	Corrected Yield for a sett weight of 4 oz.
C	46.22	46.48
D	47.47	45.67
H	46.25	44.95
E	44.05	43.65
A	42.55	41.76
F	41.88	41.53
B	41.75	40.65
O	38.33	37.89

As clone 'O' is the obviously outstanding clone it may be taken against the rest.

Difference $\bar{y}_1 - \bar{y}_0 - C(\bar{x}_1 - \bar{x}_0) = - 4.48$

Standard error $= \sqrt{\text{variance of difference}} = .5763$

$t = \frac{4.48}{.5763} = 7.9$ sig. at 1 per cent.

Conclusions. From the above results it may be submitted that since significant differences have been found amongst clones originating from the same parent tuber some years previous to selection, clones are unstable. If it is assumed that clone 'O' was the only significantly different clone from the normal in the hundred-plant plot of the original clone 'A', then the change/

change has been 1 per cent after six generations from a single tuber. It may be higher but it cannot be less. From the practical aspect, clones will lose their individuality from the point of view of yielding capacity the older they become.

Clone testing for yield is an arduous and time consuming procedure which, in view of the above results, might be to some degree unrewarding unless periodic reselection for yield were carried out.

APPENDIX.

PART I.

A.

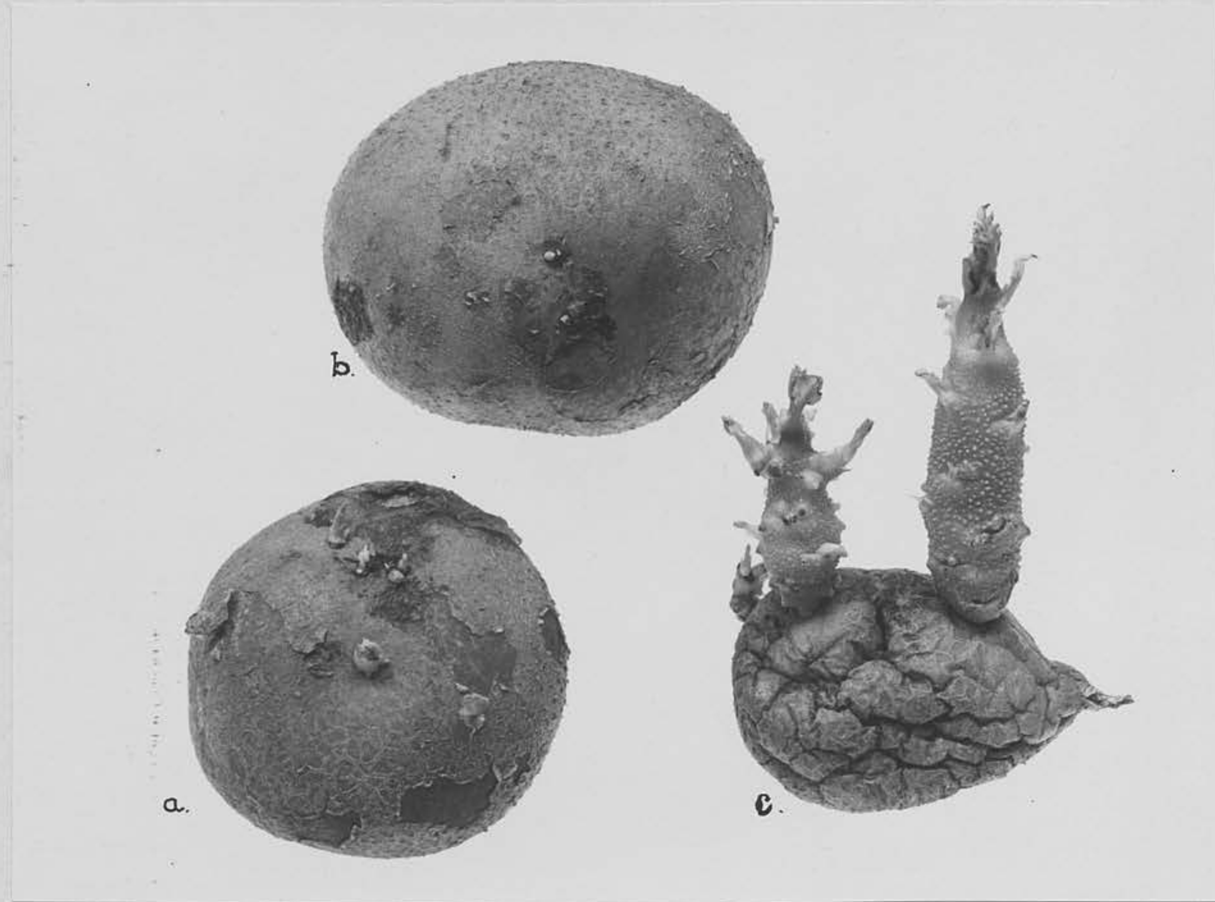
1. The apical sprout initial of a tuber at the point of visible sprouting; 0.45 mm. in length.

2a. Blighted and healthy tubers of the variety "Epicure" were all apparently healthy when stored at 80°F. on the 26th August. After thirty-five days blight had completely penetrated the tissues of the diseased tubers. These produced sprouts ½-inch in length (arrowed) as against the normal tubers approaching minimal visible sprouting.

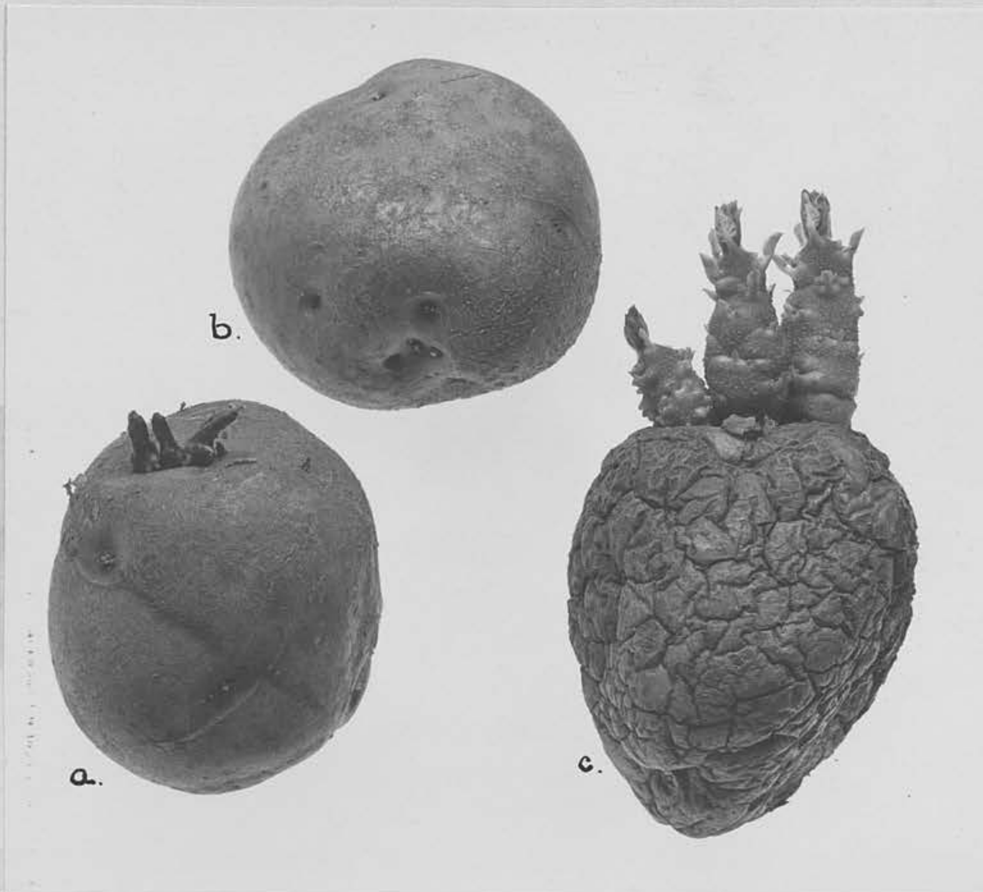
2b. A healthy and a diseased tuber of the variety "Kerr's Pink" from the same crop and condition of storage. This shows the final effect of disease on the rate of sprout growth. The rot here is associated with, but not yet proved to be due to, the fungus "black dot" (Colletotrichum atramentarium Berk & Br.).

3. Tubers of the variety "Majestic" damaged by frost and undamaged tubers from the same plant all stored in normal shed storage, showing the effect of a partially healed wound on the period to visible minimal sprouting, already passed, and on subsequent sprout growth.

B.



Up-to-Date



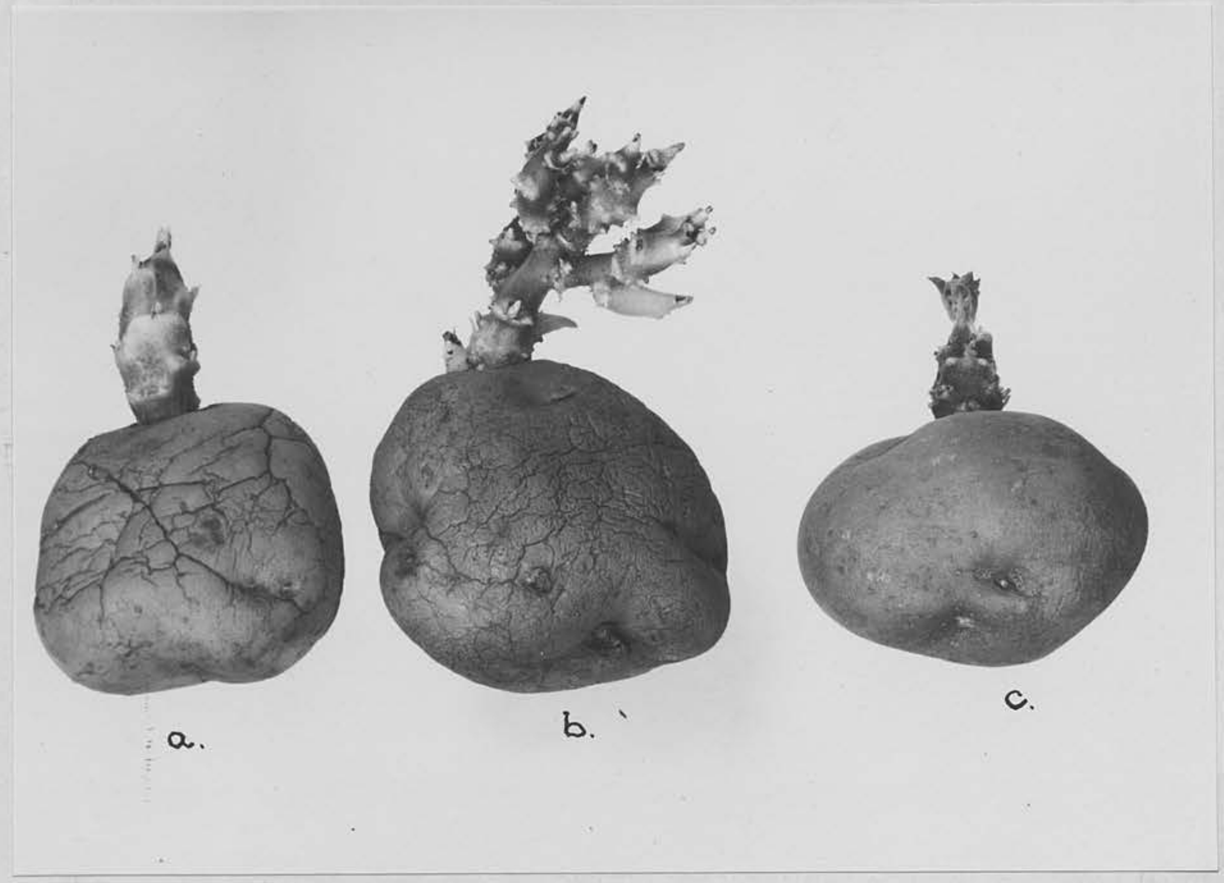
Redskin

4. Tubers of the varieties "Up-to-Date" and "Redskin" stored for five months at

a. Air temperatures above 32°F. in light.

b. 35°F., dark, and

c. 80°F., dark.



5. Tubers of the variety "Epicure" after seven months storage at 80°F.

a.	Approximately 40 per cent	relative	humidity,	dark.
b.	Do.	95 per cent	do.	do.	do.
c.	Do.	95 per cent	do.	do.	light.

(6) A.

(6) B.

C.

6. The effect of Ethylene chlorhydrin treatment (0.5 cc. per litre air space for forty-eight hours) on the sprouting of tubers stored at 80°F. (variety "Great Scot").

A. After seventy days in storage.

B. After eighty-eight days in storage.

C. After one hundred days in storage.

7. Tubers of the variety "Dunbar Standard" after five months in storage at a temperature of 50°F. (± 5) in the dark.

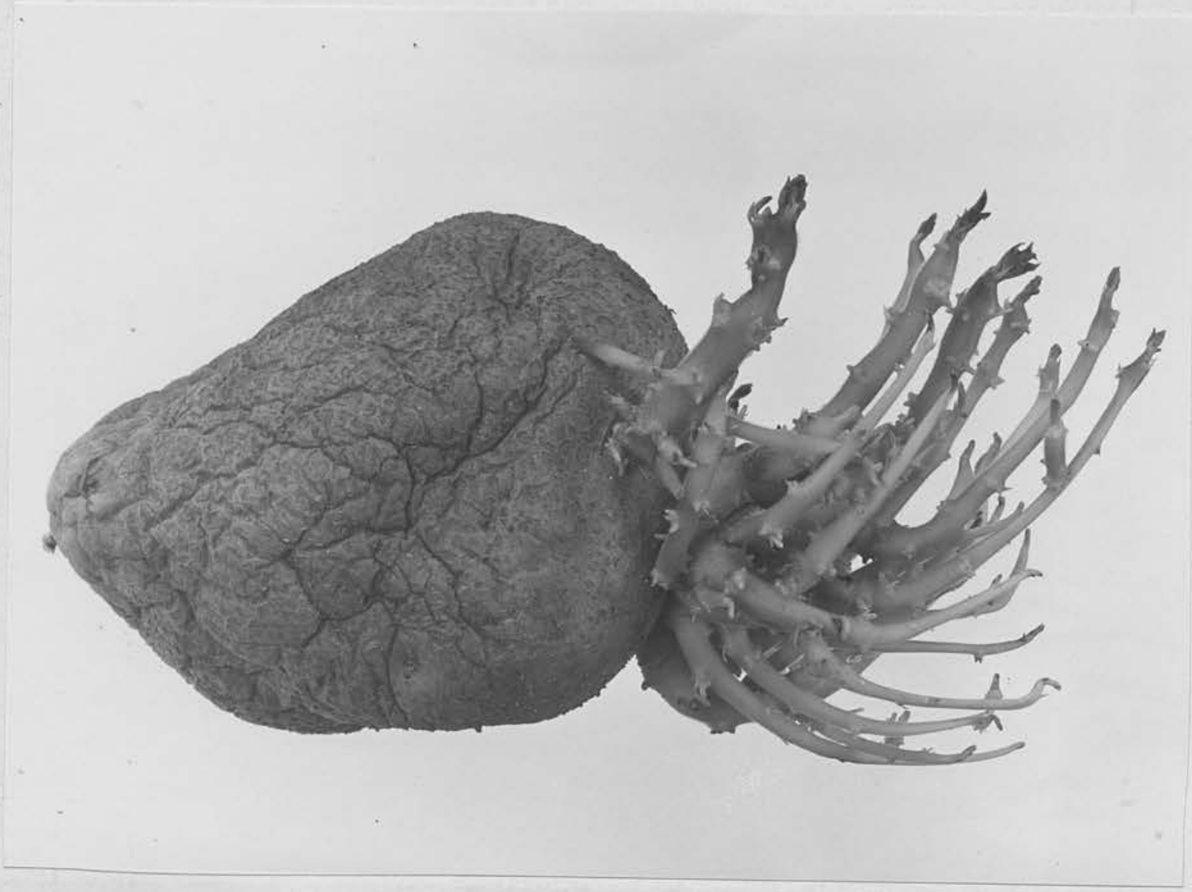
8a.

b.

8. a. Tubers of the variety "Epicure", "Majestic" and "Dunbar Standard" after eleven months in storage at 35°F. in the dark.

b. The same tubers after seventeen months at 35°F. in the dark.

D.

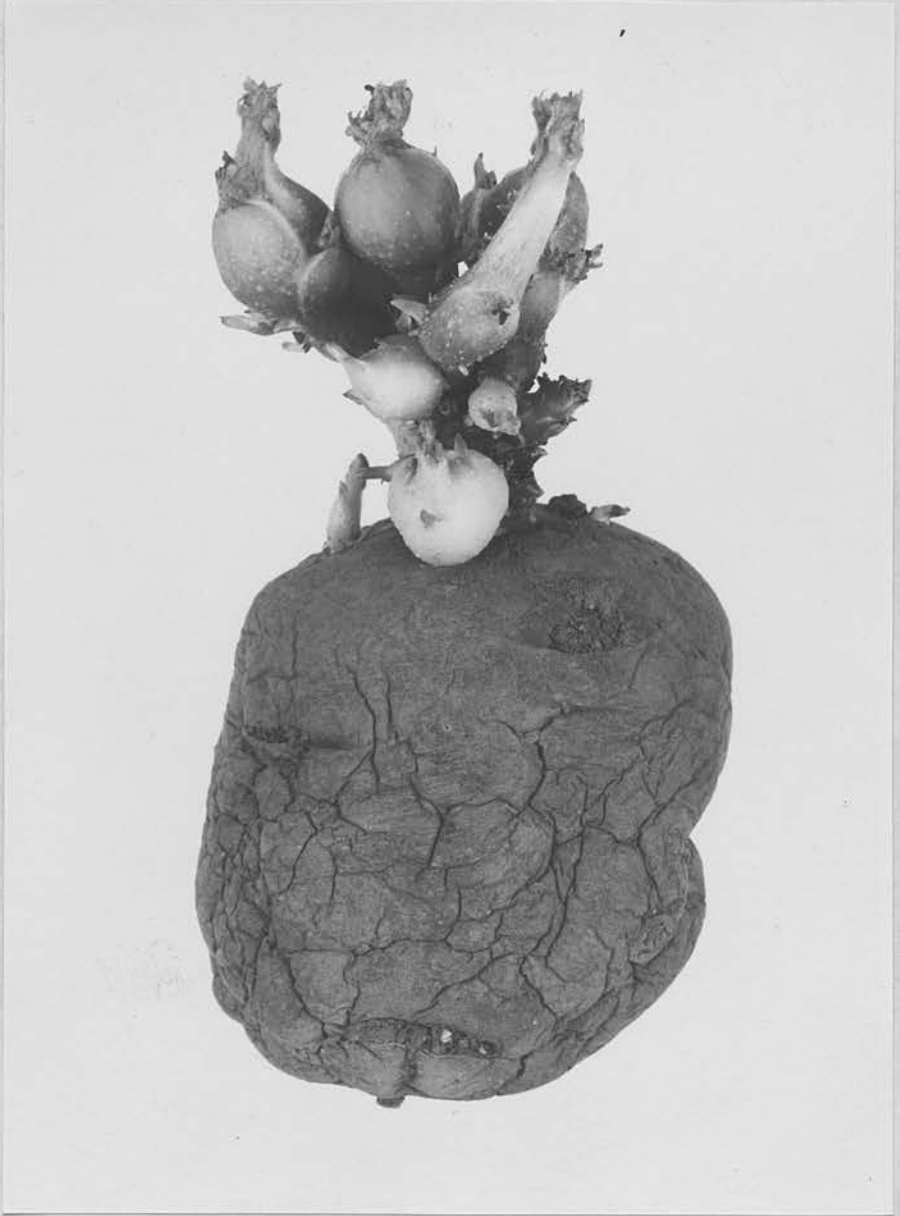


9 a.

b.

9. a. A tuber of the variety "Dr. McIntosh" stored at 80°F. showing sprout proliferation due, in the first place, to damage to the apice of the sprout.

b. The same tuber some weeks after planting. The weather conditions having been adverse for growth immediately after planting. The symptoms are typical of the condition of "little potato".



10. A tuber of the variety "Epicure" transferred from storage at 80°F. to storage at 35°F. in March. Photographed in June. Showing symptoms of "little potato".

PART II.

11. A simple piece of equipment designed to facilitate the measurement of tubers.

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13./

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ATTACHMENTS IN SUPPORT.

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Vol. 21, No. 82, 1953.

EXPERIMENTAL EVIDENCE OF CLONAL VARIATION AFFECTING YIELD IN POTATOES.

T.M.W. Davidson[1] and D.N.Lawley[2]

Whenever selection of potato plants is carried out with a view to improving the health of stocks, the possible presence of high- and low-yielding clones becomes of first importance. With the establishment of the Virus-tested Seed Scheme in Scotland, where single clones are tested for virus X, multiplied for a few years, then passed into the general seed trade, the progeny from any one clone may run into hundreds of acres. It is desirable therefore, that should there be clonal variation in yield, only families with high-yielding capabilities should be used.

In Australia (1) it was found that from the old-established varieties of Up-to-Date, Early Carmen, and Brownell, clones of earlier and later maturity than the normal could be selected readily. Some were distinct (medium and late Brownell) whilst in others (Up-to-Date) few foliar differences were observed. Although Bald (1) is more concerned with maturity variants suited to certain environments he found 'variant clones of Up-to-Date and Brownell that are consistently/

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consistently capable of outcropping other clones of similar maturity when grown under certain environmental conditions'. To date the main clones of differing maturity observed in Scotland are those of semi-bolter and bolter types. Variations of foliage form and colour of flower and tuber are found, but before 1945 no variation had been found which outcropped the typical plant of the variety and retained the same maturity date as the latter (2). One may safely assume, as did Bald, from the evidence of frequent changes in the noticeable characters which are familiar to seed-potato growers, that comparable changes in the more obscure characters, i.e. yielding capacity, occur at least with equal frequency.

Clone testing has been carried out on a large scale in Holland (3) since 1950 to prevent low-yielding, virus-tested clonal families from reaching the open market. The tests are carried out at three centres over a period of 3 years by the General Netherlands Inspection Service. It has been shown that the productive capacity of certain clones is higher than that of others, no abnormalities being manifest. The results are mainly based on the yields from small plots in uniform fields and it is not stated whether these have been statistically analysed.

The findings of workers in other countries indicate that in established potato varieties, clones of differing yielding capacity arise which may or may not differ from the normal in appearance. The latter are important from the point of view of recognition, and, once identified, may then be propagated to give increased yield. To the many specialized seed-potato growers who practise plant-selection as a means of improving their stocks, the result of this experiment will be of interest and any improvement in crop-yield resulting from the work will doubtless benefit all potato growers.

Methods and materials. Assuming that yield variants arise in the same proportion as gross variants, then the older the variety the greater the proportion of yield variants which can be expected in an apparently normal crop. On this assumption an old variety was chosen for the experiment. Another requirement was to exclude as far as possible virus disease, particularly that caused by virus X. In the virus-tested stocks available at the time, choice of variety and more particularly of clones was too restricted. This limited the choice to varieties field-immune from virus X and A, e.g. Epicure and King Edward. The former, however, was ruled out because of the frequent occurrence in it of bolters and semi-bolters. King Edward may not be entirely ideal as every plant of this variety is a symptomless carrier of the virus E (Para-crinkle), but it was adopted as the best available at the time.

In 1950 twenty typical King Edward plants were chosen from two large stock seed plots growing at East

Craigs, Edinburgh, and were lifted at maturity. From these, eight clones were selected to give the maximum weight range. Five setts from each were planted in five randomized blocks in 1951 and forty setts in forty randomized blocks in 1952. The plots were anti-blight sprayed in both seasons and no diseases were observed on the haulms or the tubers. The plots were kept under observation and were found to be free from noticeable virus diseases and foliar variations and to mature evenly.

<u>Results</u>. 1950. Eight clones selected from plots growing at East Craigs, in order of weight.

	lb.	oz.		lb.	oz.
A	3	7	G	2	6
D	3	6	F	2	0½
C	2	12½	H	1	14
B	2	9	E	1	13

1951. Five randomized blocks were planted but no statistical differences were found. The mean yields are given in order of weight.

	lb.	oz.		lb.	oz.
C	3	1¼	H	2	14
A	3	0	D	2	13¾
F	2	15	B	2	11½
E	2	14	G	2	10

1952. Forty randomized blocks were planted in a plot covering twenty drills, with each block occupying one

half/

half-drill.

As indicated by the analysis of variance below, there are highly significant differences between clones as regards yield, at the 0.1 per cent. level of significance.

Analysis of Variance of Yield (neglecting sett-weight)

	d.f.	S.Sq.	Mean Sq.	Variance ratio
Between half-drills (a and b	1	492.6	492.6	6.74 (1%S)
(remainder	38	2,157.4	56.8	..
Between Clones	7	2,635.9	376.6	5.15 (0.1 % S)
Error	273	19,956.7	73.1	..
Total	319	25,242.6	..	..

There is also a significant difference between the two adjacent plots of half-drills, a and b, each comprising twenty blocks.

On further investigation it was found that sett-weight had a small but significant effect on yield. (An increase of 1 oz. in the sett-weight corresponded to an average increase of 5.3 oz. in yield; i.e. the regression coefficient was 5.3 (± 0.6).) This would to some extent affect the comparison between clones since the mean sett-weight was not the same for each clone. The following analysis of variance of yield corrected for sett-weight shows, however, that the clones still differ significantly even when sett-weight is taken into account.

Analysis of Variance of Yield (eliminating effect of sett-weight)

	d.f.	S.Sq.	Mean Sq.	Variance Ratio
Between clones	7	1,934.0	276.3	4.93 (0.1%)
Error	272	15,250.6	56.07	..
Total	279	17,184.6	..	..

The following table gives the mean yield for each clone, the numbers in the first column being the uncorrected yields and those in the second column the yields which would have been expected if the mean sett-weight for each clone had been exactly 3 oz.

Mean Yields (oz.) per Sett.

Clone	Uncorrected Yield	Corrected Yield (for sett-weight of 3 oz.)
C	51.6	51.9
A	50.4	50.1
D	48.0	48.7
G	46.2	47.5
F	46.4	47.3
B	45.3	46.8
H	43.2	44.3
E	43.4	44.2
Standard Error	± 1.4	..

It is clear that clones A and C are well above the general average, while E and H are well below. The expected yield from 1 acre (13,000, 3 oz. setts) for clones A and C would be 18½ tons and for E and H, 16 tons.

<u>Discussion</u>. With regard to yield, it does not matter if differences are due to retrogressive mutations only, the normal form remaining constant, or to retrogressive and progressive mutations. Viruses also may mutate and the effects of different strains may cause differences in yields (4). So far, however, strains of virus 'E' have not been recorded and it has been assumed that, being uniform throughout the clones, this virus has not interfered with results.

It is possible that clones react differently in various seasons and further yield trials are necessary to study this effect. Clones A and C have maintained their yielding capacity over the 3-year period, also the range in the year of selection approximates closely the range in 1952. Too much emphasis, however, cannot be placed on the individual yields at selection or on the small yield differences in 1951. Owing to the relatively few numbers involved, the consequent absence of any statistical proof in the latter, and the random source of the former, the effect of many other factors, e.g.soil and manuring, could so influence the yield as to obscure yielding ability.

Without further work it is also impossible to state how frequently mutations affecting yields arise in potatoes. Judging from foliage mutant forms, it is unlikely that they are sufficiently frequent to permit the rapid degeneration of any high-yielding clone.

Conclusions. Assuming virus 'E' has not affected the yield, the results are of some consequence.

1. High- and low-yielding clones appear to be present in King Edward and probably in other varieties.

2. The yielding capacity of clones appears to be heritable.

3. Increases in yield per acre may be possible by selection for high yield coupled with clone testing.

The investigation is being continued to determine whether clone differences are affected by season.

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DORMANCY IN THE POTATO TUBER AND THE EFFECTS OF STORAGE CONDITIONS ON INITIAL SPROUTING AND ON SUBSEQUENT SPROUT GROWTH.

T.M.W. Davidson.

The importance of the behaviour of the potato tuber in storage needs no emphasis whether the ultimate aim be use as ware or seed. Being a living entity the tuber is highly responsive to storage environment which may determine its condition as regards cooking quality, soundness, viability and tuber behaviour when planted as seed. With the change to shed and controlled-temperature storage as opposed to older, more primitive methods, detailed knowledge is required regarding all influencing factors in various combinations and their ultimate effects. With this object in view the following experiments were conducted and observations made of these various storage factors.

In any study of storage the dormancy factor is of prime importance. A widely held view is that the potato tuber has a 'rest period', that is a period following harvest when the tuber is incapable of producing sprouts in 'optimal conditions for sprouting', or in other words, in conditions which are known to bring about sprouting in the shortest possible period of time. In sub-optimal conditions for sprouting the tuber requires a longer period to sprout, and this is called the 'dormamcy period'. This is the period of time, including the 'rest period' which the tuber requires to produce sprouts. Emilsson,[1] following on the work of others including Wright and Peacock[2] but using storage methods which did not fulfil 'optimal sprouting conditions', found that the potato tuber required from 7-19 weeks 'rest period' depending on the variety used. It will be shown that the potato tuber has no 'rest period' and that the appearance of a readily visible sprout is not a sign of dormancy-break but the first visible indication of growth which has been progressing from the time of harvest.

<u>Growth at the apical eye prior to minimal visible sprouting.</u>

Visible sprouting has been regarded as the critical sign of growth-commencement or the end of the dormancy period in the potato tuber. In order to study the possibility of growth proceeding for some time prior to visible sprouting, random samples of ten tubers each, from the same plot of the variety Majestic, were lifted at haulm maturity and stored in two batches at constant temperatures of 80°F. and 39°F. Ten tuber samples from each storage environment were examined at intervals and the lengths of the median - longitudinal section of the sprout-initials of the apical eyes were measured using a micrometer eye-piece. Apical eyes were used for this study as apical dominance in tubers is most pronounced early in the storage period. Readings were taken at intervals which appeared to be suitable for the purpose and which fitted in with other work. The mean readings are shown in Figure 1.

Figure 1. Graph showing the growth curves of the apical eye sprout-initials of potato tubers (variety Majestic) from harvest to visible sprouting at two storage temperatures. Each point is the mean of a ten tuber sample.

From Figure 1 it will be noted that growth proceeds rapidly at the sprout-initials of the tubers stored at 80°F., showing minimal visible sprouting after two weeks in storage. From this, no incapacity for growth is evident. In the same manner growth has been proceeding more slowly at the sprout-initials during storage at 39°F. When the sprout-initial attains the length of .45 mm. it becomes visible to the naked eye as a sprout. As the length of the sprout-initial at harvest is in the region of .2 mm. the increase of .25 mm. occurs within the period of apparent tuber dormancy (Figure 2).

Figure 2. An apical sprout-initial of a tuber at the point of visible sprouting, .45 mm. in length.

The effect of storage conditions on the length of the period from harvest to minimal visible sprouting.

In this experiment, fourteen varieties comprising four first earlies, seven maincrop and three late maincrop were used. The stocks were free from virus and other diseases and were grown together in plots of thirty plants were variety. The plots were harvested at haulm-maturity except in the case of the three varieties noted in Table 1, which were harvested after the haulms had been killed by frost.

The tubers from each variety after harvest were divided into four equal lots of from 50-100 tubers and placed under different storage conditions. Reasonably constant temperature chambers were used except in the case of normal shed storage. It was expected that the tubers stored at 68°F. (±5°F.) would be in optimal conditions for sprouting and those at 80°F. (±5°F.) in maximal conditions. A cold store at a temperature of 35°F. (±2°F.) was used to store tubers in minimal conditions for sprouting. The approximate relative humidity is given in Table 1 but it will be shown later that humidity and also light have no influence on the length of the period from harvest to minimal visible sprouting at least in the higher range of temperatures.

Table/

Table 1. Days of harvest to minimal visible sprouting of tubers in different storage conditions.

Variety	Maturity	Harvest date 1955	Average days to minimal visible sprouting: 90-95% humidity 80°F.	90-95% humidity 68°F.	Normal storage at concurrent air temps. and humidity with heating during frost	95-100% humidity 35°F.
Epicure	1st Early	20/8	45 ≠ (33)	64	97 (75)	177 (101)
Ulster Chieftain	1st Early	29/8	46	57	97	136
Home Guard	1st Early	29/8	28	34	-	73
Arran Pilot	1st Early	10/9	39	47	68	82
Record	Early Maincrop	16/9	32	46	87	109
Arran Consul	Early Maincrop	11/10	30	43	135	150
King Edward	Early Maincrop	13/10	28	32	89	141
Orion	Early Maincrop	19/10	31	39	100	138
Dr.McIntosh	Early Maincrop	19/10	13	21	47	87
Majestic	Early Maincrop	19/10	21 (22)	41	89 (80)	136 (120)
Redskin	Early Maincrop	20/10	20	22	69	136
* Kerr's Pink	Late Maincrop	20/10	13	20	45	84
* Golden Wonder	Late Maincrop	20/10	38	39	117	151
* Up to Date	Late Maincrop	20/10	20	22	65	93

≠ Bracketed figures are for a second year of test.

* Haulms killed by frost.

Environmental factors and their effect on the length of the storage period to minimal visible sprouting.

Some account must be given at this point of the effect of environmental factors.

Temperature. The temperature of storage appears to be the primary environmental factor influencing the length of the storage period to minimal visible sprouting. The viability range of sound tubers is from just below freezing point, in the region of 30°F. for a few hours to 120°F., also for a few hours. The temperature giving the shortest period of storage to minimal visible sprouting is in the neighbourhood of 80°F. and that giving the longest period 35°F. or possibly a degree or two lower (Figure 3).

Figure 3. Days from harvest to visible minimal sprouting for tubers of fourteen varieties, comprising approximately 1,000 tubers per storage condition. The curve 'Air temperatures' is for shed stored tubers at concurrent air temperatures above freezing point. The difference between varieties in different storage conditions is shown by the plotted path of two varieties (Arran Pilot and Dr. McIntosh).

Humidity. The humidity of storage has apparently no effect on the length of the period to visible sprouting at high temperatures (Table 2) but may have some effect at lower temperatures of storage although this is thought to be slight.

Light or dark conditions. These conditions have no effect on the length of the period to minimal visible sprouting (Table 2) and it is thought to have no effect at lower temperatures.

Table 2. The effect of humidity and light on the length of the storage period to visible minimal sprouting in storage at 80°F. for samples of 250 tubers.

Storage conditions	Average storage period in days to minimal visible sprouting		
	Dark Relative Humidity 40%	Light Relative Humidity over 90%	Dark Relative Humidity over 90%
Variety			
Epicure (1st Early)	33	33	33
Majestic (Maincrop)	26	21	22

Inherent factors and their effect on the length of the storage period to minimal visible sprouting.

Variety. Varieties differ one from another in many ways but the behaviour within the variety is relatively stable, thus the storage period to visible sprouting per variety is found to be fairly constant; the higher the storage temperature the narrower are the limits of spread about the mean period of sprouting. From Table 1 it will be noted that there is a general correlation between varietal earliness in ripening and a relatively long period from harvest to minimal visible sprouting at the higher storage temperatures. In Figure 3 results with two varieties have been plotted to show the difference between varieties in relation to the individual periods of storage required for visible sprouting at different temperatures.

Other inherent factors have been reported in literature as affecting the length of period to visible sprouting namely: Size of tuber (1)(3); degree of tuber maturity (1)(2)(4)(5); starch content (3).

Size of tuber. This appeared to have no appreciable effect.

Degree of tuber maturity. Immature tubers were found to require a longer period of storage to minimal visible sprouting in all storage conditions.

Starch content. The variety Golden Wonder is relatively rich in starch and it may be observed from Table 1 that it was outstanding amongst the late main-crop varieties in requiring a longer storage period to minimal visible sprouting in all storage conditions. The effect of variation in the starch content of individual tubers within the variety has not been examined but it is not thought to have any appreciable effect.

Foliage variants. Tubers of feathery wildings were tested against normal tubers of the variety Majestic but little variation was found in the period of storage to minimal visible sprouting required at all storage temperatures.

Virus diseases. These were found to have little effect on sprouting with the exception of virus Y infection which required an appreciably longer period to sprout at 80°F. and 35°F. than the normal.

Non-environmental factors and their effect on the length of the storage period to visible sprouting.

Fungal diseases. Tubers infected with dry rot (*Fusarium coeruleum*), severe common scab (*Streptomyces scabies*) or other organisms have a shorter period of storage to visible sprouting than have the healthy tubers of the same variety at the same storage temperatures.

Wounds. Tuber wounds which heal quickly, such as clean cuts and indentations, have no effect, whereas slow healing or partially healed wounds such as frost damage, is usually accompanied by a certain amount of rot which affects the storage period to minimal visible sprouting in the same way as infection by fungal disease (Figure 4). It appears that a certain amount of fungal or bacterial rot is associated with the shortening of the period to minimal visible sprouting at temperatures lower than optimal.

Figure 4. Majestic tubers, frost damaged and normal from the same plant, stored in normal shed storage showing the effect of a partially healed wound on the rapidity of visible sprouting and on the consequent growth.

Chemical Treatment. Many chemical treatments of tubers can be used to shorten the period of storage to minimal visible sprouting ('dormancy breaking'). The author has found that Ethylene chlorhydrin (.5 cc. per litre air space) can shorten the period of storage to minimal visible sprouting even under optimum conditions. It is interesting to compare the results given in Table 1 with those of Stuart and Milstead [6]. Storage at 80°F. is apparently almost as efficient a means of 'dormancy breaking' as the use of chemical treatments but there is no doubt that in the lower and normal range of storage temperatures tubers can be made to sprout more quickly by the use of such chemical treatments.

Work has been conducted to test the effect of oxygen concentration on the breaking of the 'rest period' of tubers but the clear cut results obtained by Thornton [7] were not substantiated by Sawyer and Smith [8].

Discussion on the period from harvest to minimal visible sprouting.

Visible sprouting or an arbitrary sprout length has been regarded previously as the critical sign of growth commencement from potato tubers. From the above results it has been found that growth appears to be continuous at the apical eye after harvest (Figure 1) and the growth rate is dependent on the storage temperature alone, light having no effect and humidity having possibly some slight effect only at low storage temperatures. The growth at the apical eye being dependent upon the temperature, there is no question of dormancy existing in potato tubers but only a natural conditioning for perennation from one season to the next. If the term 'dormancy' implies absence of visible growth then the potato tuber may be dormant for periods of up to five months in conditions sub-optimal for sprouting but if the term infers incapacity for growth then the potato tuber has no dormant period.

The appearance of a general correlation between varietal earliness of ripening and a relatively long storage period required to visible sprouting at 80°F. is interesting. (Table 1). This character may be a necessary factor for earlies which, maturing in the height of the summer, should not sprout rapidly in spite of favourable growing conditions existing at and subsequent to harvest. This factor may be due to selection by breeders and growers or possibly by a natural selection of genes, where an early variety in natural conditions would sprout and grow into a young plant to be inevitably destroyed by the first frost of the winder. In storage at 35°F. visible sprouting is delayed for nearly five months and, as will be shown later, growth thereafter is extremely slow.

<u>The effect of storage conditions on subsequent sprout growth after minimal visible sprouting</u>.

After minimal visible sprouting occurs, light, humidity and temperature play compensating roles in their various combinations. Of these, temperature is the primary factor then light and lastly humidity.

At high temperatures (80°F.) sprout growth is mainly independent of humidity and light. Sprouts appear within a few weeks after harvest (Table 1) and growth is rapid for several weeks by which time the sprouts vary from ½-inch to 1-inch in length, thereafter growth slows down and thickening of the sprout occurs, the length at the end of the storage period (March-April) being ¾ to 1 inch. The effect of humidity and light may be judged from Figure 5 where high humidity and dark conditions have promoted growth in the latter part of the storage period.

Figure 5. Tubers of the variety Epicure after seven months storage at 80°F. Left: approximately 40% relative humidity, dark. Centre: approximately 95% relative humidity, dark. Right: approximately 95% relative humidity, light.

At room and at winter air temperatures above freezing point access to light is the primary factor in controlling sprout growth. Minimal visible sprouting occurs on the average about 11 weeks after harvest and thereafter the rapidity of growth is dependent on light access, other conditions being equal. This may be observed in general by comparing a typical tuber of Redskin after five months storage in boxes in light at normal air temperatures (Figure 6A) and tubers of the variety Dunbar Standard after five months storage at 50°F. in the dark (Figure 7).

Figure 6./

Figure 6. Tubers of the variety Redskin stored for five months at

A. Air temperatures above 32°F. in light

B. 35°F., dark; and

C. 80°F., dark.

Figure 7. Tubers of the variety Dunbar Standard after five months storage at a constant temperature of 50°F. (± 5°F.) in the dark.

In low-temperature storage (35°F.) minimal visible sprouting takes place, on the average 17 weeks after harvest and sprout growth thereafter is slow, with light access and humidity having for all practical purposes only a slight effect up to the end of the normal storage period.

It will be noted that the Redskin tuber shows minimal visible sprouting after approximately twenty weeks in storage (Figure 6B). At normal planting time in March and April, tubers of all sixteen varieties tested over two seasons were sound, with sprouts of ½-inch or so in length. Tubers stored at 35°F. remain in excellent condition for longer periods than those normally required. The tubers remain sound and sprout growth is very slow. (Figure 8).

Figure 8. A. Epicure tubers after eleven months; B. Majestic and C. Dunbar Standard tubers after 10 months at 35°F. in the dark.

Discussion. To keep the sprout growth of stored tubers to a minimum is the aim of all growers whether the ultimate use be ware or seed. It is equally important from the point of view of 'seed' exporters where long distances and hot conditions are involved. There is no doubt that cool storage at constant temperatures varying from 35 - 38°F. are ideal for storage and transport, giving a sound end product with very little sprouting. Samples cooked along with controls showed the quality of tubers from cool storage to be unaffected when boiled. Flesh colour is intensified during cool storage and flavour becomes more apparent. In tubers destined for chipping, storage at temperature above 40°F. is advocated by Smith[9] but, without inhibitors, sprouting under these conditions would be excessive as all tubers for consumption must be kept in the dark. Tubers for 'seed' can be kept in excellent condition at normal room air temperatures provided there is good access of light. A graph of the combined effects on sprouting of temperature and light is shown in Figure 9. Humidity plays only a minor role in increasing the rapidity of sprout growth.

<u>Figure 9</u>. Graph of the combined effects of temperature and light on the rapidity of sprout growth.

<u>The effect of storage on subsequent development of the potato.</u>

To observe the after effects of storage on field performance. tubers from the three varieties

King Edward, Golden Wonder and Arran Consul, from three storage treatments, were planted in nine separate random blocks. The tubers were planted at a double spacing of three feet between plants to allow for sample liftings during the growing season and to obviate the effect of removing plants upon the remainder. Five plants of each variety from each storage condition were harvested at fortnightly intervals after tuberization and their yields recorded (Table 3).

Table 3. Yields of fifteen plant samples, five per variety of three maincrop varieties, King Edward, Golden Wonder and Arran Consul.

Storage treatment	Weeks from planting							
	11	13	15	17	19	21	23	25
	lbs	lbs	lbs	lbs	lbs	lbs	lbs	lbs
80°F.	4	17	31	52	59	70	75	81
Air temperature	½	8	25	49	66	73	75	80
35°F.	-	3	24	40	57	64	73	73

Plots of five varieties were also planted from tubers stored in the same storage conditions as the above and were used for general observation and pilot yield trials (Table 4).

Table 4. Pilot yield trial of the effect of storage temperature on subsequent maturity and yield.

Variety	Storage treatment: 80°F. Yield†	80°F. Date of Maturity	Normal shed storage at concurrent air temperatures with heating during frost Yield†	Normal shed storage Date of Maturity	35°F. Yield†	35°F. Date of Maturity
	lbs		lbs		lbs	
Arran Pilot 1st Early	69	11/8	84	15/8	96	26/8
Record)Early	57	15/8	85	28/8	89	10/9
Majestic)Main-	105	14/9	127	20/9	125	*
Orion)crop	111	18/9	137	*	126	*
Kerr's Pink)Main-	112	*	114	*	116	*
Up to Date)crop	135	*	122	*	123	*

† Yield figures are for 27 tubers planted.

* Not matured when the haulms were killed by frost 21st September, 1956.

Discussion. Although the scope of the above experiments is limited the effect of storage on yield has since been confirmed by statistical experiment. With all the varieties grown, plants from tubers stored at 80°F. emerged on the average fourteen days before those tubers which were shed stored at concurrent air temperatures above freezing point. The latter emerged on the average eight days before these stored at 35°F. The difference in vigour was obvious between the three treatments until almost mid season, eleven weeks after planting. In the early varieties where maturity of the haulm was unimpeded by frost the warmer the storage the earlier was the maturity (Table 4). The term maturity is used as meaning the point at which maximum yield is obtained and is judged by the yellowing of the senescent haulm. From Table 3 it will be noted that the warmer the storage the earlier tuberization takes place and in those varieties that reached maturity unimpeded (Table 4) the warmer the storage the lower was the final yield. So, from the practical point of view, cool-stored tubers, although later in emerging and in tuber forming, eventually catch up, and, in the case of varieties unimpeded by frost, outyield warmer-stored tubers at maturity. Where earliness of cropping is important fairly warm storage (45-50°F.) in boxes with good light access might be advantageous.

<u>Other Features</u>. The incidence of the spread of rot diseases in cool storage has not been studied specifically but there is evidence that cool-stored tubers are less able to seal-off inoculated material of the gangrene fungi (*Phoma foveata* and *P. tuberosa*) than those tubers stored at a higher temperature although infection of tubers dipped in a spore suspension was much less at the lower temperature in the presence of moisture.(10) In the tests reported here which covered three seasons the tubers were kept in boxes in a cool store at a constant temperature of 35°F. where they remained sound and

free from rots. A feature of warm storage is the incidence of 'little potato', a physiological condition where the life cycle is contracted, as evidenced by the production of young tubers on the sprouts of the old 'sett' (Figure 10B). The conditions may be induced artificially by transferring sprouted tubers from warm to cold storage (Figure 11). From experiments carried out by the author warm storage alone will not produce 'little potato', three factors being involved, viz. 1 warm storage, 2 proliferated sprouting due to injury of any form to the apical sprout or sprouts and 3 a cool period after planting. The condition may be permanent, as shown in Figure 10B, but all degrees of severity may be found in the field as a result of variation of the influencing factors.

Figure 10. A. Tuber of the variety Dr. McIntosh stored at 80°F. showing sprout proliferation due to damage to the apical sprout. B. The same tuber some weeks after planting, the weather conditions having been cool.

Figure 11. A tuber of the variety Epicure transferred from storage at 80°F. to storage at 35°F. in March. Photographed in June.

Conclusions.

1. Sprout growth is continuous at the apical eye of potato tubers after harvest. There is no incapacity

for growth, but this growth is not visible to the naked eye as a sprout for a period of time, depending on the storage conditions.

2. Temperature is the prime factor in controlling the length of the period from harvest to minimal visible sprouting; humidity may have some effect in the lower temperature range but light has no effect.

3. Cool storage at 35-40°F. is ideal from the point of view of the soundness of the end product and minimum sprout growth. Where tubers are stored for seed purposes at higher temperatures light access is essential to prevent etiolation.

4. In general, the warmer the storage conditions the earlier is tuberization and maturity with a lower final yield than cooler-stored tubers.

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