STUDIES ON TRANSMISSION AND DEVELOPMENT OF INFECTION BY *OOSPORA PUSTULANS* ON POTATOES

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CONTENTS

SUMMARY

1. Studies were carried out on the transmission and development of Oospora pustulans infection upon the underground parts of potato plants. In comparing the relative importance of tuber-borne and seed-borne inoculum, it was concluded from the studies that seed infection is the major source of spread and development of infection upon the subsequent crop. Adding inoculum to the soil, did not alter the pattern of colonisation of plants, associated with seed-borne inoculum, while higher levels of seed infection resulted in more disease occurring within the crop. Soil type, however, was found to modify subsequent disease development, higher levels of infection being associated with heavy, clay soils, compared with light, sandy soils. The level of severity of disease symptoms on tubers was also considerably influenced by storage conditions of temperature and humidity: humid conditions and low temperatures favoured disease development.

2. In studies on the overwintering of O. pustulans in different soils, either sterilised or unsterilised prior to inoculation, levels of recovery were only appreciable in sterilised soils. Only one of six unsterilised soils examined showed infection 21 months after inoculation.

3. In studies of the effect of applying different amounts of water to soil during the later part of the growing season upon skin spot development, higher levels of infection were associated with increased amounts of water applied.

4. Increased level of seed infection gave delayed emergence, increased blanking and lower main stem numbers. More severe infection of seed also reduced tuber numbers of the subsequent crop and reduced seed yields. Ware yields, however, tended to be unaffected or were increased. At a wider plant spacing (16 in.), reductions in total weight yields occurred with increased levels of seed infection but at a closer plant spacing (11 in.), total weight yields were less affected, as a result of compensatory growth.

5. Investigation of factors at lifting and of seed tuber treatments, in relation to skin spot control, showed that time of haulm destruction had no effect upon subsequent skin spot development but that higher levels of infection occurred with delay in time of lifting. Boxing of tubers at lifting was found to give reasonable control of skin spot but only with early lifted tubers. At later times of lifting, satisfactory control was achieved only with boxing accompanied by organo-mercury disinfection. Boxing and, to a greater extent, boxing and disinfection gave some control when applied after clamp storage, following lifting but their effectiveness decreased with extended clamp storage and was no longer at a satisfactory level when applied six weeks after lifting.

6. Storage temperature variation was found to affect disease development, in that prolonged storage of tubers at high temperatures (9°C), gave reduced levels of skin spot infection, in comparison with extended storage of tubers at low temperatures (4°C).

7. Boxing and organo-mercury disinfection of seed tubers at lifting, resulted in more rapid plant emergence, less blanking and increased tuber numbers, compared with untreated tubers. Similar stimulation of crop growth was also obtained from boxed tubers stored at high temperatures (9°C).

8. In attempting to find satisfactory alternatives to organo-mercury solution in tuber disinfection for control of skin spot, of the fungicides used, only Benlate (Benomyl), proved as effective as organo-mercury compounds.

GENERAL INTRODUCTION

Historical

Skin spot disease of potato tubers appears to have been known in Scotland as far back as the mid 19th century: according to Moore (1959), a disease of tubers known as "Pock and Blind eye" was described by Johnstone (1846). The symptoms of this disease, then attributed to insect damage, were in the form of numerous small pimples covering the tuber and loss in sprouting ability of affected eyes.

A more detailed account of the disease was given in England by Carruthers (1904), who received from Lincolnshire a sample of potatoes covered with numerous bluish black 'warts', about $\frac{1}{4}$ in. in diameter. By taking thin peelings of these 'warts', Carruthers found that underneath lay a brown patch of infected tissue which was separated from healthy tissue by the presence of a well-defined cork layer. Closer examination of the peelings showed that the cells of the infected tissue were permeated by very fine threads of a fungal mycelium but due to an absence of fructifications, identification of this fungus was not possible.

Pethybridge (1915), who first gave the name 'Skin spot' to the disease, managed to obtain a strong fungal growth on exposing sections of diseased tissue to a moist atmosphere. This fungus was identified as Spicaria solani but it could only be provisionally regarded as being the causal organism, since no inoculation experiments were carried out. Further observations as to the pathogen concerned were made by Milburn and Bessey (1915), who suggested Spicaria nivea, and by O'Brien (1919), who

favoured Rhizoctonia crocorum. Güssow (1918), on the other hand, considered skin spot to be physiological in origin rather than the result of infection by some pathogen. He claimed that the prevalence of the disease in badly ventilated storage cellars, where the tubers had been covered with soil as protection against frost, was the direct result of inhibition of the normal respiration of the tubers.

The first really comprehensive account of skin spot was given by Owen (1919), who, along with Wakefield, identified the causative organism as being Oospora pustulans (Owen and Wakefield). Owen gave a detailed account of the morphology and growth in culture of the pathogen and of symptoms of infection on potatoes. However, inoculation experiments carried out with O. pustulans, in an attempt to produce skin spot symptoms on tubers, were not entirely successful and there still remained some doubt as to the pathogenicity of O. pustulans, in relation to the disease.

Evidence of the continued confusion lies in the fact that Wollenweber (1920), gave an account of a tuber disease which from his description and illustration was skin spot but which he attributed to infection by Phoma eupyrena. Furthermore, Shapovolov (1923), stated that skin spot as a disease in its own right did not exist but that the pustules were merely a primary stage of powdery scab (Spongospora subterranea), and that O. pustulans was only a secondary invader of the pustules.

Millard and Burr (1923), however, confirmed the earlier findings of Owen (1919). By carrying out inoculation experiments with both O. pustulans and S. subterranea, they were able to show

that skin spot and powdery scab are two separate and quite distinct diseases and that O. pustulans is, in fact, the causal organism of skin spot.

Pathogen

Oospora pustulans (Owen and Wakefield) is a member of the Hyphomycetales (Fungi Imperfecti). The hyphae of the fungus are extremely fine, 2-4 μ in diameter, closely septate and hyaline or pale brown in colour but become thicker (7-10 μ), knotted and dark brown with age (Owen, 1919; Kharkova, 1961a).

The conidiophores range from 80-100 μ in length and are usually erect, subtending oval-cylindrical or cylindrical, single-celled, hyaline conidia with rounded ends, 6-12 μ x 2.0-2.5 μ. The conidia are produced acropetally and either terminally or laterally, resulting in a fan-like spread of the conidial chains.

The occurrence in ageing cultures of small, black sclerotial bodies, ranging in diameter from 49 μ - 1 mm., which germinate to give normal colonies of O. pustulans when dried and placed upon a nutrient medium, has been reported by Kharkova (1961a) and by Lennard and Boyd (1965). Similar bodies have also been isolated from potato roots by Hirst, Hide and Stedman (1965).

Growth of the pathogen was found by Owen (1919) to occur with a wide range of solid and liquid media. The most rapid and luxuriant growth, however, was obtained with media of cooked vegetable tissues such as potato, carrot and parsnip. Kharkova (1961b), found that best development of O. pustulans occurs with media containing sugar and related this to the high levels of

skin spot infection associated with conditions producing high sugar concentrations in potato tubers i.e. low temperatures.

The optimum growth temperature of the fungus is around 15°C with growth virtually ceasing at temperatures as low as 0°C and as high as 25°C (Owen, 1919; Salt, 1957; Kharkova, 1961b). Kharkova (1961b) reported that cultures of O. pustulans were able to survive such extreme temperatures as -39°C during winter and, for up to two hours at 52-56°C, without reduction in spore viability.

The fungus grows best at pH 6.2-6.8 with growth being inhibited below or above this range and finally ceasing at pH 4 and 10 (Kharkova, 1961b).

Symptoms

Because of the smallness of the area of infection and because such infection is confined to the outer tissues only, O. pustulans is considered to be a weak parasite of potato tubers.

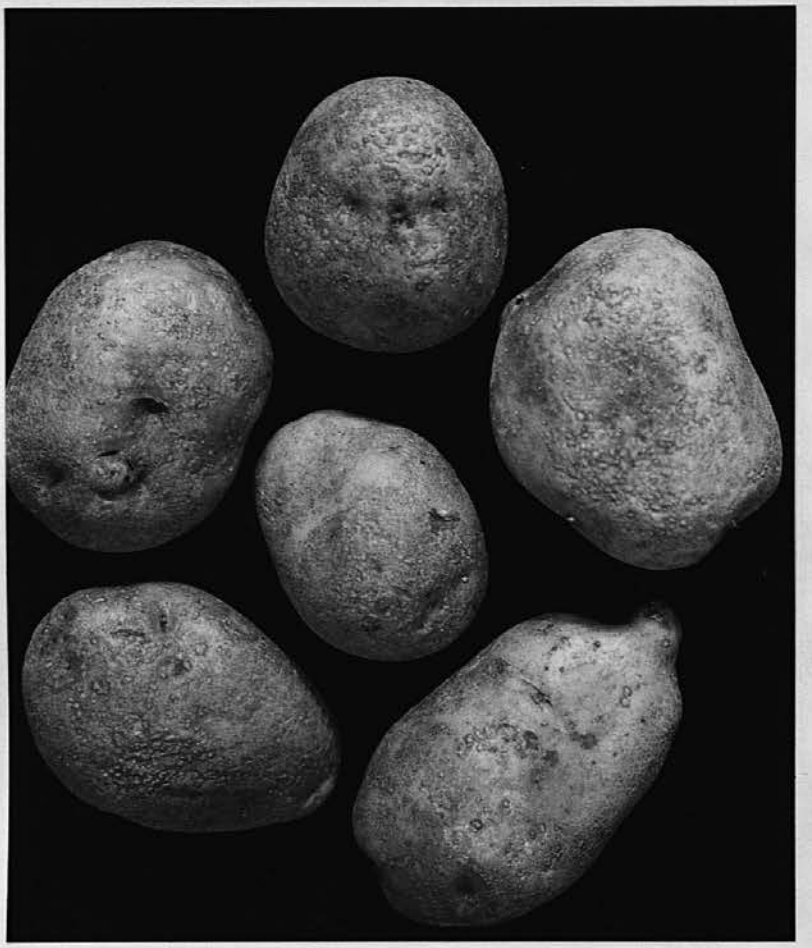
Although the external symptoms of tuber infection may appear about two months after harvesting, it is usually only after four to five months storage of the tubers that they become fully developed, under the normal field conditions experienced in Britain (Allen, 1957; Boyd and Lennard, 1961b). Even then, the tubers normally require washing before the full extent of infection can be properly assessed.

The symptoms consist of small, circular lesions, purple black in colour, which are found on the surface of the tuber and which rarely extend to more than 1 mm. in diameter and 2 mm. in

depth. They may occur separately, each lesion corresponding to a separate infection site or, if they are numerous, may coalesce to result in an extensive blackening of the tuber surface.

Tubers showing slight and severe skin spot infection, with all eyes infected, are shown in Plate, fig. 1 and 2.

Plate, fig. 1. Tubers showing slight skin spot infection, with all eyes infected.



Plate, fig. 2. Tubers showing slight to severe skin spot infection, with all eyes infected.

Owen (1919), stated that the form of the lesion depended upon the particular potato variety infected. She distinguished between thick-skinned varieties, such as Arran Chief, where the lesions developed as definite pimples with the tuber skin being stretched tightly over them, and thin-skinned varieties, such as King Edward, where the lesions consisted of small sunken dark spots which were never raised as in the pimple form. Millard and Burr (1923), observed both forms of lesion on King Edward tubers and, after observing their development, concluded that the pimple form of lesion is merely an early stage of the disease symptom which eventually develops into the sunken form of lesion.

Kharkova (1961a), stated that there are four main types of tuber symptoms, which were suggested to be the result of infection by different races of the pathogen. She classified the symptoms as:- (1) Superficial lesions. (2) Prominent roundish pustules often with pressed in edges. (3) Flat lesions of irregular form, and (4) Deeply depressed, roundish, pitted areas. Lesions similar to the latter two categories were reported in Britain, on tubers treated with the sprout depressant - Isopropyl phenyl carbamate (I.P.P.C.), (Ives, 1955) and on tubers which were overwintered in the ground (Boyd and Lennard, 1961b).

As well as infecting potato tubers, Hirst and Salt (1959) and Salt (1964), have also shown that O. pustulans can infect the root systems and underground stems of potato plants. They succeeded in isolating from brown lesions, found in the cortex of the underground parts of Majestic plants, a fungus whose morphology and pathogenicity, in relation to potato roots and tubers, was found to be identical to those of O. pustulans.

Economic effects

With regard to ware tubers, skin spot infection is of little economic significance, since the areas of infection are easily removed upon peeling of the tubers. The tubers may, however, be badly blemished and this can result in reduction of their market value, more especially with the increasing commercial practice of washing and pre-packing of tubers prior to marketing.

The major economic importance of the disease is related to infection of seed tubers and, in particular, to eye infection of these tubers, causing the death of bud tissues.

Owing to the inconspicuous symptoms of the disease, tubers with eyes badly infected may often be planted quite unwittingly along with healthy seed tubers. As a result, subsequent plant emergence will be irregular with infected tubers failing to produce plants, or showing delayed plant emergence.

Total crop yield may not necessarily decrease, where skin spot infection gives rise to blanking, due to compensatory growth by neighbouring plants (Boyd and Lennard, 1961a; Hirst, 1967; Hirst, Hide, Stedman and Griffith, 1973). The proportion of ware to seed tubers, however, does tend to be affected, there being an increase in the percentage ware and a corresponding decrease in that of seed tubers, as the amount of blanking due to skin spot infection becomes greater (Boyd and Lennard, 1961a; Hide, Hirst and Stedman, 1973). This, of course, would give rise to concern if a crop was being grown for seed purposes.

Boyd and Lennard (1961a), also indicated a reduction in total tuber number, more especially seed tuber number, to be another effect of planting skin spot infected seed. This may be

due to damage to a proportion of the eyes on each tuber and a consequent reduction in the number of main stems produced or may, as suggested by Salt (1958), be the result of subsequent skin spot infection of stolons, decreasing the amount of tuber initiation.

Transmission

Since increasing levels of seed infection result in increasing levels of infection of the subsequent crop, there appears little doubt that the major source of infection for transmission of the disease to the subsequent crop, is the seed tuber (Boyd and Lennard, 1961a; Hirst, Hide and Stedman, 1965; McGee, 1967). Boyd and Lennard (1961a), found, however, that infection of crops grown from seed tubers with no apparent skin spot infection, could also occur. Although Hirst and Salt (1959), reported the occurrence of eye infections which may not be detected macroscopically, Boyd and Lennard (1961a) also obtained infection on produce from disease free seed which had been surface sterilised and considered this an indication that O. pustulans is a normal inhabitant of certain soils and may also be found in virgin potato soils as suggested in 1932 (Anon.).

The occurrence of O. pustulans in soils which have not grown potatoes for periods ranging from one to ten years, using rooted potato stem cuttings and tomato seedlings as indicator plants, has also been reported (Hirst and Salt, 1956; Salt, 1957; Nagdy, 1962; Hirst, Hide, Griffith and Stedman, 1970). In addition, the formation of micro-sclerotia, after decomposition of O. pustulans infected underground potato plant parts was reported by Kharkova (1961a) and confirmed by Hide (1970), who

found a few microsclerotia able to produce spores after seven years burial in soil. This ability of the fungus to survive in soil therefore suggests it is capable of persisting through the rotations existing in seed growing areas (Hirst et al, 1970).

Infection of tubers

Infection of tubers is considered to occur at or just prior to normal lifting, when they are approaching maturity (Greeves and Muskett, 1939; Allen, 1957; Edie and Boyd, 1966). Boyd (1957), has also shown that, with Arran Pilot and King Edward varieties, seed tubers are slightly less susceptible to infection than ware tubers, presumably because of their relative immaturity.

Although most infection occurs around normal lifting time, further infection may also occur during subsequent storage of the tubers. Edie (1964) and Hide (1968), have shown that the percentage eye infection of King Edward tubers has increased during amp storage, probably as a result of the prevailing conditions of high humidity. Kharkova (1961a) reported the presence of conidia of O. pustulans in the air of a potato store, claiming that this would promote infection of the tubers in the store.

Artificial inoculation of potato tubers, using a spore and mycelial suspension of O. pustulans, followed by anatomical sectioning of the inoculated areas, has shown that the primary mode of entry of the fungus into the tubers is via the lenticels (Allen, 1957). This had already been suggested by Greeves and Muskett (1939). Allen found that, shortly after inoculation, fungal hyphae, presumably of O. pustulans occurred in the outer cortex of the sections and were always

opposite a lenticel. Furthermore, he found that storage of the tubers, after inoculation, in conditions of high humidity encouraged the development of subsequent skin spot. This he attributed to the mechanism of lenticular opening whereby conditions of high humidity result in the cells underlying the lenticels becoming turgid, therefore causing the lenticels to open and hence facilitate the entrance of the fungus. As a second channel of infection, Allen suggested the buds of the eyes and the area between, which is unprotected by a cork cambium. In the absence of a cambium, the fungal hyphae can readily penetrate the unprotected epidermis of the eye. From the results of skin spot assessments on samples of tubers lifted at different times, Lennard (1967), has suggested a more rapid establishment of eye infection than surface infection in the field.

Fuchs (1954) has stated that O. pustulans is a wound parasite and that potatoes injured in harvesting are particularly liable to infection. In support of this, Boyd and Lennard (1961a), found that upon washing Kerr's Pink tubers, involving brushing to assist in removal of soil, followed by artificial inoculation with a spore/mycelial suspension, the subsequent skin spot pustules were distributed in lines upon the tubers, apparently corresponding to previous brush marks. Kharkova (1961a), also reported the infection of tubers via surface wounds, following early lifting of the crop, i.e. when the periderm was not fully mature and therefore easily damaged at lifting.

Investigations into the internal structure of skin spot pustules were carried out by Owen (1919), and by Millard and Burr (1923). A mature pustule, upon sectioning, extends to a depth of 1-2 mm., corresponding to 12-15 cell layers of the tuber cortex. The fungal hyphae are easily seen within many of these cells, the walls of which appear to be thickened and cuticularised. The starch grains of affected cells entirely disappear. Interspersed with the cuticularised cells are groups of clear cells with thin, hyaline walls. These cells are also more or less empty but nuclei, starch grains and cytoplasmic contents, in varying stages of degeneration, may often be seen. The progress of the fungus is apparently retarded by the cuticularisation of the cell walls but is also affected by the presence of a well-defined cork-layer, often six or more cells deep, which encloses the pustule and extends on either side to within a few cells of the outer periderm. In some cases, successive cork layers may be formed.

From artificial inoculation experiments, Allen (1957), has shown that all damage to the cortical tissues takes place very soon after infection. Degeneration of the periderm to the outside of this infected tissue, however, does not occur until at least two months after infection, so explaining the time lag from time of infection to the appearance of visible symptoms of the disease.

Factors affecting the incidence of skin spot

Infection of potato tubers by O. pustulans is present to some extent every year but is particularly prevalent after wet growing seasons, (Boyd, 1957). Boyd (1960), also associated

high levels of skin spot with low temperature conditions during box storage of tubers.

In an attempt to relate the general annual incidence of skin spot to weather conditions, Boyd and Lennard (1962), examined climatic figures over a 34 year period (1927-60): above average rainfall during the lifting period (September 21 - October 31) in the seed producing areas of Scotland, and below average temperature during the first three months of storage (October-December), showed a close relationship with above normal incidence of skin spot in the following spring.

Any delay in lifting, thereby exposing tubers to lower soil temperatures will also encourage skin spot development, as was found by Edie and Boyd (1966). High levels of skin spot infection have been obtained with high humidity, both before and after infection (Allen, 1957), and low temperature and high humidity during storage (Edie, 1964).

The importance of the seed inoculum, as a factor determining the incidence of skin spot, is also recognised, higher levels of seed tuber infection tending to increase infection in the resulting crop (Boyd and Lennard, 1961a; Hirst, Hide and Stedman, 1965; McGee, 1967).

Soil type also contributes to subsequent skin spot development. In Russia it has been suggested that infection is most severe on a sandy-podzol soil (Khrobrykh, 1959) and that greater infection occurs on a ferruginous podzol than on peat boggy soil (Gomolyako, 1959). In Britain, Salt (1964), examined O. pustulans infection of stem bases, stolons and roots of different varieties grown in various soils and concluded that

stem base infection was least in neutral peat and alluvial soils, more on light loam and most on clay soils.

Varietal susceptibility

That different varieties differ in their susceptibility to infection by O. pustulans, has been indicated by Anon. (1932) and Boyd (1957). From field trials involving up to 24 commercial varieties, Craigs Alliance, Kerr's Pink, Craigs Royal, Sharpe's Express, King Edward and Ulster Chieftain appear to be most susceptible whereas low susceptibility is shown by Golden Wonder, Dunbar Rover and Dunbar Standard (Boyd and Lennard, 1961a).

Boyd and Lennard (1961a), suggested that such differences in varietal susceptibility may be attributed to differences in skin characters, resulting in varying degrees of resistance to penetration by the fungus. Nagdy and Boyd (1965), after artificial inoculation of tubers of 30 commercial varieties, attempted to relate subsequent levels of surface infection to varietal differences in the following periderm characteristics:- (a) Total thickness, (b) Average numbers of rows of cells in the periderm, (c) Thickness of the suberin layer, and (d) Percentage crude fibre present (i.e. cellulose, hemicellulose and lignin). A highly significant negative correlation was found between surface infection and each of those skin characters.

A highly significant correlation was also shown by Nagdy and Boyd (1965), between levels of surface and eye infection. It was pointed out, however, that severe surface infection will not always be accompanied by severe eye infection since such factors as humidity and temperature conditions of storage, may

encourage one in relation to the other. Other factors in the tubers may also influence their response to infection, notably vigour of sprout growth, e.g. tubers of King Edward and of Arran Pilot may show an equally severe eye infection but in the field the eventual loss in plant establishment may be quite different.

Control

Control of skin spot has been achieved by dipping seed tubers, at lifting, in an organo-mercury solution ($\frac{1}{2}$-1 minute dip), accompanied by subsequent box storage (Greeves and Muskett, 1939; Boyd, 1960; McGee, 1967). Time of lifting was found by Greeves and Muskett (1939), to have no influence upon the effectiveness of the treatment but Edie and Boyd (1966), found that delay in time of lifting was associated with a reduced level of control. This was related to the fact that skin spot development is, to a large extent, governed by temperature: any delay in lifting would normally involve lower temperature conditions of soil and subsequent storage and thus encourage skin spot development.

Organo-mercury disinfection seldom eradicates completely the skin spot pathogen from potato tubers and is ineffective against any surviving inoculum during crop growth (Hide, Hirst and Griffith, 1969). Furthermore, it creates a health hazard to operators and it is not always practicable to apply, on a commercial farm at the optimum time desirable, i.e. at lifting of the crop. Attempts have therefore been made, not only to find alternatives to organo-mercury disinfection but also to

find suitable methods of control which do not involve tuber disinfection.

Recent attempts at chemical control have included the use of systemic materials whose fungicidal action may perhaps survive at least the early part of tuber growth in the field, so combatting infection from soil-borne inocula, during growth of the crop. Hide, Hirst and Griffith (1969), reported the effects of two such compounds, both benzimidazoles. Thiabendazole, when applied as a dip immediately after lifting, gave marked control of skin spot during winter storage of King Edward seed tubers. This control extended well into the following growing season, so that at lifting of the subsequent crop, skin spot incidence was lower than that occurring upon tubers grown from untreated seed. Benomyl, when applied as a dust immediately before planting, reduced considerably the incidence of skin spot, both during growth and at lifting of the subsequent crop, compared with that obtained from tubers grown from untreated seed.

Effective skin spot control has also been achieved by the fumigation of seed tubers, using sec-butylamine (2 aminobutane), (Graham and Hamilton, 1970). Fumigation within 48 hours of lifting (200 mg. fumigant per kg. tubers) gave excellent control of both surface and eye infection of both King Edward and Majestic tubers, without any phytotoxic effects.

Boxing of seed tubers at lifting, without disinfection, has been found to reduce subsequent levels of skin spot infection but not to the same extent as with disinfection (Boyd, 1957, 1960). This reduction may be attributed to the exposure of tubers to dry conditions which would check fungal activity at

the tuber surface (Lennard, 1967). Under field conditions, however, boxing of tubers after lifting only reduces skin spot infection to any extent, if lifting is carried out early (Edie and Boyd, 1966; McGee, 1967). Lennard (1967), related this in part to higher ambient temperatures, at earlier times of lifting, rendering the boxing treatments more effective and indicated that where higher temperatures, about 10°C, could be maintained, exposure of tubers to dry conditions at later dates of lifting can give some skin spot control. He also suggested that skin spot would be difficult to control in normal conditions of bulk storage due to difficulties involved in maintaining low humidities.

Boyd (1957), found that early haulm removal resulted in reduced infection, thus suggesting that susceptibility to skin spot is related to the maturity of the tubers. McGee (1967), however, failed to show any significant reductions in subsequent skin spot development, with either box or clamp tuber storage, as a result of early haulm removal.

A marked decrease in the incidence of O. pustulans in seed multiplication stocks has been achieved with tubers initially derived by vegetative propagation from rooted stem cuttings (Hirst, Hide, Griffith and Stedman, 1970). Even after two years in soils in rotations, plants originally from rooted stem cuttings can be much less infected by O. pustulans than most commercial crops. Such 'healthy' stocks, however, require several years for multiplication and will therefore be exposed to re-infection by O. pustulans from e.g. soil, machinery and equipment or from other tubers with which they may be stored.

Thus, to maintain their health, Hirst et al consider that practical methods of sterilising machinery and equipment must be devised and the application of fungicides to the tuber stocks, continued.

Introduction to experimental work

The experimental work was designed to obtain more information relating to the transmission of skin spot disease of potatoes, the factors affecting its establishment, its effects upon the yield of field crops and aspects concerning the control of the disease.

The work may be considered in the following sections:-

A. Factors associated with the transmission and development of infection by Oospora pustulans on potatoes and the effects of skin spot infection upon crop growth.

B. Treatments for the control of skin spot in relation to subsequent field effects and skin spot development in the following crop.

GENERAL MATERIALS AND METHODS

Since the importance of skin spot relates mainly to infection of seed tubers causing delayed emergence and possible blanking of the subsequent crop, seed-sized tubers were used throughout the experimental work, i.e. tubers which would pass through a $2\frac{1}{4}$ in. riddle but not through a $1\frac{1}{4}$ in. riddle. The variety used was King Edward, it being highly susceptible to skin spot infection, particularly to eye infection (Boyd, 1957; Boyd and Lennard, 1961a; Nagdy and Boyd, 1965).

Emergence rate

To assess the rate of plant emergence from planted seed tubers of any treatment, weekly counts of the number of plants emerged were made throughout the growing season until numbers became constant. A plant was considered to have emerged if any of its parts had broken the surface of the soil. The rate of emergence was then calculated by multiplying the number of newly emerged plants counted each week by the number of days from planting and dividing the sum of the products by the final number of plants emerged (Boyd and Lennard, 1961a).

Assessment of surface infection

Assessment of general surface infection of tubers was made using the standard method described by Boyd (1957).

After washing, the tubers were assessed for extent of infection according to the following scale:-

1. Severe (S) - 25% or more of the surface area affected.
2. Moderate (M) - 10-25% of the surface area affected.
3. Slight (L) - trace - 10% of the surface area affected.
4. Trace (T) - up to 10 pustules present.

A surface infection index (S.I.I.), for any sample of potatoes was then calculated by multiplying the numbers of tubers in each category by the average percentage area infected, severe x 62.5, moderate x 17.5, slight x 5.0, and trace x 1.0.

The total of these products was then divided by the total number of tubers examined (N), in the sample and multiplied by 100/62.5 to give a mean percentage area affected.

Thus the mean surface infection index,

$$S.I.I. = \frac{(62.5S + 17.5M + 5L + T)}{62.5N} \times 100$$

Although subject to personal bias by the assessor, this method is reasonably well-standardised to enable consistent assessments to be made by different workers.

Assessment of eye infection

(a) Visual assessment. Visual assessment of eye infection of tubers was made according to the method described by Nagdy and Boyd (1965). After washing of the tubers, eye infection was assessed by noting the presence of skin spot pustules within the "depression" of the eyes. Tubers were then recorded as having "all", "some", or "no" eyes infected. For simplicity, it was assumed that tubers with some eyes

infected had 50% of the eyes attacked. An eye infection index (E.I.I.), for any sample of potatoes was then calculated by multiplying the number of tubers with all eyes infected (A) by 100 and the number with some eyes infected (S) by 50, and dividing the sum of the products by the total number of tubers examined (N).

Thus,

$$E.I.I. = \frac{50(2A + S)}{N}$$

(b) Microscopic assessment. Such assessment is necessary since the eyes of tubers may be infected with O. pustulans although neither pustules nor damage to the eye tissues may be apparent (Hirst and Salt, 1959). The technique used, involved excising tuber eyes and incubating them in a humid atmosphere at about 15°C. Aerial conidiophores develop upon the eye tissues, and are easily identified under the microscope (Hide, Hirst and Salt, 1968).

Most tuber samples consisted of 40 tubers selected at random. After washing, 50 eyes, also taken at random, were excised, using a 3/8 in. diameter cork borer fitted with a spring-loaded plunger. The plunger, used to eject the tissue, had a concave end to reduce damage to the eye and also ensured a uniform depth of "eye-core" excised. After excision, the eye-cores were placed upon damp paper towelling within plastic boxes which, when closed, ensured a humid atmosphere.

The cores were incubated at about 15°C, in darkness, for five days. Microscopic examination of the eyes was then made, using a stereoscopic microscope at the usual magnification of x 40.

EXPERIMENTAL WORK

SECTION A Factors associated with the transmission and development of infection by Oospora pustulans on potatoes and the effect of skin spot disease upon crop growth.

Previous work has indicated that the skin spot organism is commonly tuber-borne but can survive in soil, perhaps over a rotational cycle, and that the level of severity of the disease may be influenced by soil conditions during growth and at the time of lifting, and environmental conditions during storage. It has also been shown that the effects of planting seed tubers infected by skin spot include delayed and possibly reduced plant emergence, a reduction in numbers of tubers produced in a crop and possibly a reduced crop yield. The experiments in this section were carried out to investigate further aspects of disease transmission and the development of infection on potatoes, and to attempt to evaluate the relative importance of tuber and soil-borne infection and the influence of different environmental factors on disease levels. Account was also taken of the effects of planting infected seed tubers on crop growth. The experiments are considered under the following headings:-

A_1 The effect of level of seed infection and soil type upon plant emergence, yield and skin spot infection of the crop.

A_2 The effect of level of seed infection and *O. pustulans* inoculum in sterilised and unsterilised soils upon *O. pustulans* infection of underground stems and stolons.

A_3 The over-wintering of *O. pustulans* in different soils.

A_4 The effect of varying levels of soil moisture during growth upon skin spot development of the subsequent crop.

A_5 The effect of degree of skin spot infection of the seed stock and of planting distance upon emergence and yield of the subsequent crop.

A_1 The effect of level of seed infection and soil type upon plant emergence, yield and skin spot infection of the crop

This experiment was designed to study the development of infection by *O. pustulans* on the underground plant parts and to investigate any effects which level of seed infection and soil type may have upon crop growth, yield and disease incidence.

Materials and methods

In 1968 and 1969, field trials were conducted at three separate sites which along with their associated soil types are described in Table 1.

Table 1. Details of experimental sites, 1968 and 1969.

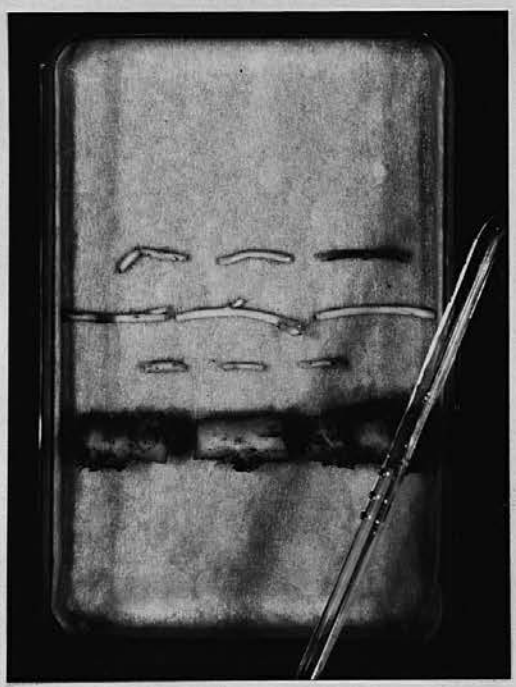
Site	Texture scale	Mechanical analysis of soils			
		Clay % (<0.002 mm)	Silt % (0.002-0.02 mm)	Coarse and fine sand % (0.02-2 mm)	Stones % (>2 mm)
Scoughall	Loamy sand	9.8	3.2	87.0	15.9
Boghall	Sandy clay-loam	21.0	14.0	65.0	36.8
Bush	Sandy clay-loam	21.0	10.0	69.0	5.8

At each site, King Edward seed tubers showing three different levels of skin spot infection, "free"; slight with infection on some eyes and moderate or severe with infection on all eyes; were planted at 12 in. (30 cm.), spacing in a randomised block lay-out, with four replicates of each infection category. The "free" seed used was taken from fourth year produce of stem cuttings, originally free from skin spot (Hirst and Hide, 1967). Although

this seed was free from macroscopic symptoms, 3% of eyes in 1968 showed the presence of O. pustulans, after incubation at 15°C for five days. In 1969, no O. pustulans infection of the tuber eyes was detected. In order to reduce possible cross-contamination between replicates to a minimum, each replicate was isolated by planting only alternate drill lengths.

Weekly emergence counts were taken from 31 May and 30 May in 1968 and 1969 respectively, until plant numbers remained constant. From the counts, the average numbers of days for plants to emerge was calculated for each seed infection category, at each site. At four times during the growing season lifts were made, when two plants per replicate in each treatment were harvested for examination. In cases where the percentage blanking was high, only one plant per replicate was lifted at the later harvest dates. Assessments of stem and tuber numbers and tuber yield were made. From each plant, the underground portion of one main stem was selected and all roots and stolons removed with the exception of three stolons positioned respectively upon the main stem, near ground level; near the point of attachment of the stem to the seed tuber; and at a point mid-way between these two (Plate, fig. 3). After washing, the stem and stolons were assessed separately for degree of surface browning. The stolons were then detached from the stem and, along with the stem, were each divided into three equal lengths. All parts were surface sterilised in a 1:20 solution of Deosan (Sodium hypochlorite) for 1 min., rinsed in distilled water for 1 min. and incubated at 15°C for five days (Plate, fig. 4). After incubation, all parts were examined with a stereoscopic

Plate, fig. 3. Underground potato stem with three stolons, selected for subsequent incubation.



Plate, fig. 4. Incubation of underground potato stem and stolons.

microscope (x 40) and the percentage of the upper surface area showing sporulating O. pustulans was assessed for all 12 portions of each plant. The remaining plants of all treatments were harvested on 15 or 23 October (1968) and 6 October (1969), the tubers being boxed and held in an insulated store at 4°C until the following March, when assessments of skin spot development were made. In addition, in 1969, samples of all treatments, harvested on 6 October, were placed in small cardboard boxes and held at 3°C and 10°C, under conditions of either high or low humidity. Four boxes of ten tubers were used for each treatment. Assessments of skin spot development were made in March for tubers stored at 10°C and in June, 1970, for those stored at 3°C.

Details of seed infection categories, dates of planting and lifting and numbers of tubers planted per plot are given in Table 2.

Table 2. Details of seed infection categories, dates of planting and lifting and tuber numbers planted per plot, 1968 and 1969.

Site	Level of seed infection	Dates of planting and lifting		Tuber number per plot	
		1968	1969	1968	1969
Scoughall	Free from visible infection Slight, some eyes Moderate-severe, all eyes	Planting dates:- 30 April Lifting dates:- 15 July 12 August 9 September 8 October 15 October	6 May 15 July 13 August 9 September 6 October	20	15
Boghall	Free from visible infection Slight, some eyes Moderate-severe, all eyes	Planting dates:- 29 April Lifting dates:- 15 July 12 August 9 September 8 October 23 October	20 May 15 July 13 August 9 September 6 October	20	15
Bush	Free from visible infection Slight, some eyes Moderate-severe, all eyes	Planting dates:- 8 May Lifting dates:- 15 July 12 August 9 September 8 October 23 October	23 May 15 July 13 August 9 September 6 October	15	15

Results

The results are considered as follows:-

(1) Plant emergence and percentage blanking.

(2) Stem number.

(3) Tuber number.

(4) Tuber weight yield.

(5) Surface browning of underground stems and stolons.

(6) *O. pustulans* infection of underground stems and stolons.

(7) Skin spot infection of the subsequent crop.

(8) Skin spot and *O. pustulans* eye infection of subsequent crop after storage (1969 only).

1. Plant emergence and percentage blanking. The results for average rates of emergence and percentage blanking obtained in 1968 and 1969 are shown in Table 3. Emergence rates for all levels of seed infection in all soils tended to be slower and percentage blanking appeared to be slightly higher in 1969 than in 1968. It is not known, however, why blanking with severely infected seed, planted in loamy sand, was so high in 1969. The low, but nonetheless, consistent blanking found in all soil types with skin spot free tubers in 1968, was the result of gangrene infection, as verified by examination of the tubers which failed to emerge.

In both 1968 and 1969, with all soil types, increased seed infection resulted in delayed plant emergence and, in the case of more severe seed infection, an increase in the percentage blanking.

At all levels of seed infection, the most rapid rates of plant emergence in both years was found with loamy sand, the rates for both sandy clay-loam soils tending to be similar.

The relationship found between degree of blanking and soil type was less consistent.

Table 3. Rate of emergence and percentage blanking of King Edward seed tubers in relation to level of seed infection and soil type, 1968 and 1969.

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Level of seed infection	Average number of days to emergence		% Blanking		Average number of days to emergence		% Blanking		Average number of days to emergence		% Blanking	
	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969	1968	1969
Free, no eyes	37.9	40.1	2.0	0.0	47.5	52.8	2.0	0.0	50.7	59.0	2.7	0.0
Slight, some eyes	42.4	46.9	3.0	0.0	54.0	63.1	0.0	0.0	53.5	63.5	1.3	3.3
Moderate-severe, all eyes	48.7	61.3	24.0	65.0	66.4	70.7	33.0	38.3	65.1	76.9	44.0	46.7

2. Stem number. No significant differences were found in the average numbers of main stems (stems growing from the seed tuber), for the different harvest dates. Lateral stem numbers (all branches from the main stems), also showed no significant variation for the different harvest dates, apart from a slight seasonal variation with plants from the loamy sand. The stem numbers, in relation to level of seed infection and soil type, averaged for all harvests, are shown in Fig. 1(a) and (b), (Appendix I(a), (b) and (c)).

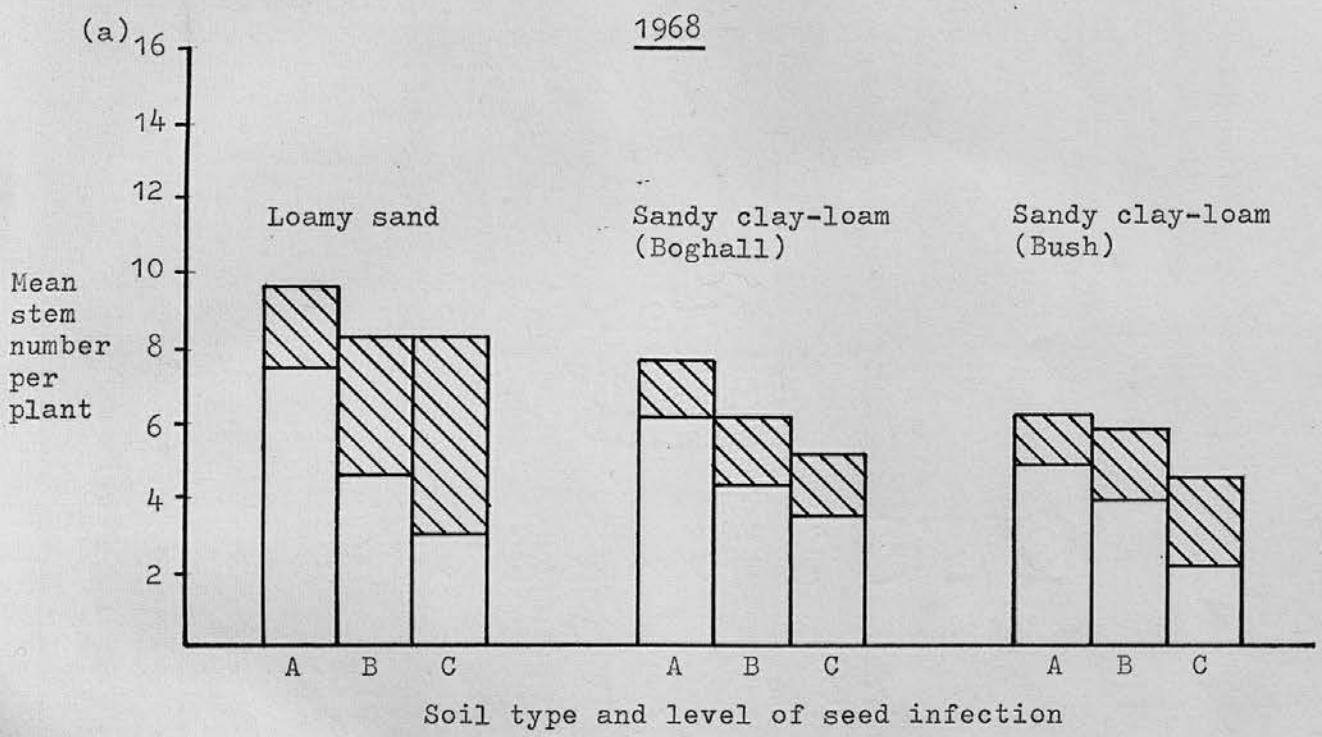
In all soils, increased level of seed infection, in both 1968 and 1969, resulted in decreased numbers of main stems produced, but this was usually accompanied by increased lateral stem production. Thus total above-ground stem numbers for all categories of seed infection planted in each soil were more or less similar, although they still tended to be higher with skin spot free seed. The main exception was found with loamy sand in 1969 where, due to increased lateral branching, total stem number increased with increase in level of seed infection.

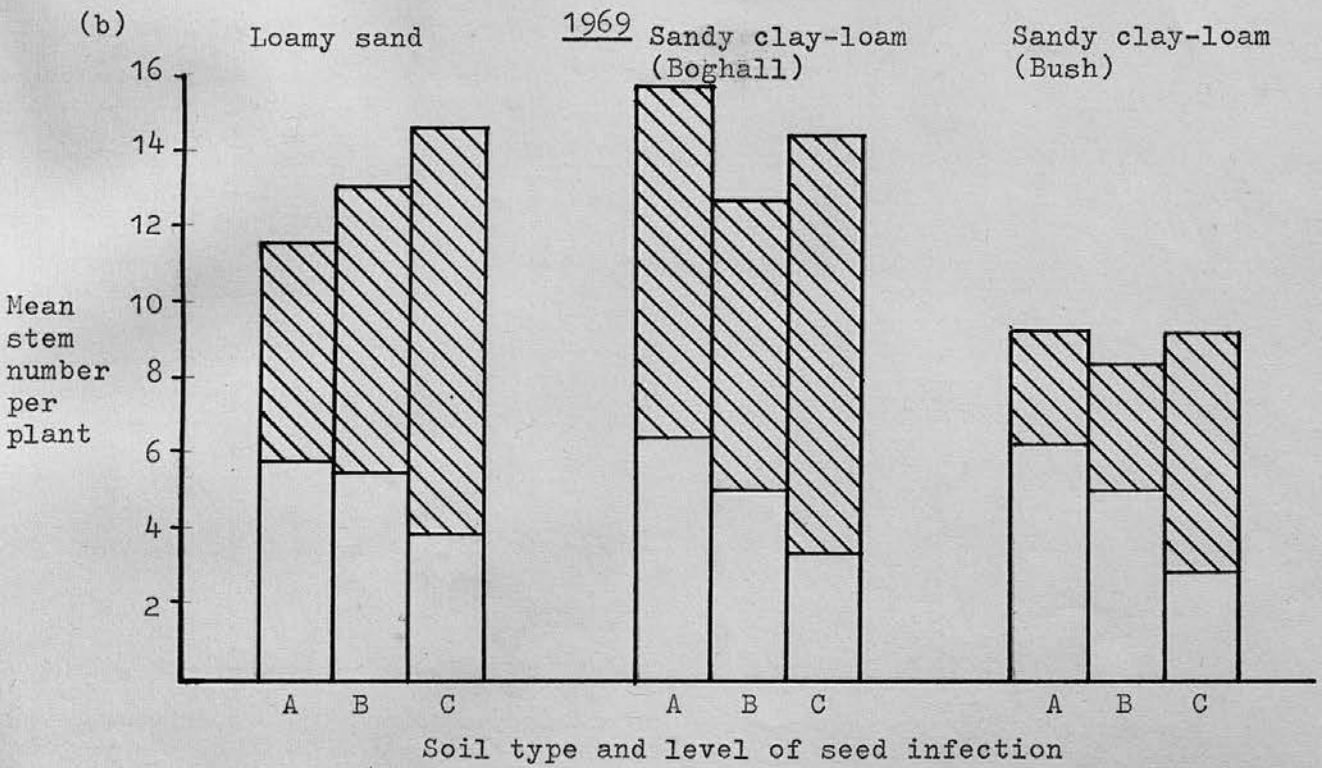
With all levels of seed infection, there was no marked effect of soil type upon main stem number. However, total stem numbers were generally lower from sandy clay-loam (Bush) in both years.

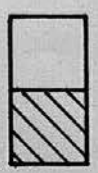
3. Tuber number. The effects of level of seed infection, time of harvest and soil type upon total number of tubers formed per plant in 1968 and 1969 are shown in Fig. 2(a)-(f), (Appendix II(a), (b) and (c)).

Total tuber numbers for all categories of seed infection, in all soils, increased from July to August or September and then showed a decline. Milthorpe and Moorby (1966), have indicated that those tubers formed during the first two to three weeks, following the appearance of the first tubers, are the only tubers to grow to any appreciable size and that many formed later are usually reabsorbed. The tendency for tuber number to decrease at later lifting dates in loamy sand, however, may also be attributed in part, to rabbit damage as "scrapings" and partly consumed tubers were observed in both years.

Fig. 1. Mean main and lateral stem number per plant in relation to level of seed infection and soil type, 1968 and 1969.







Seed infection categories

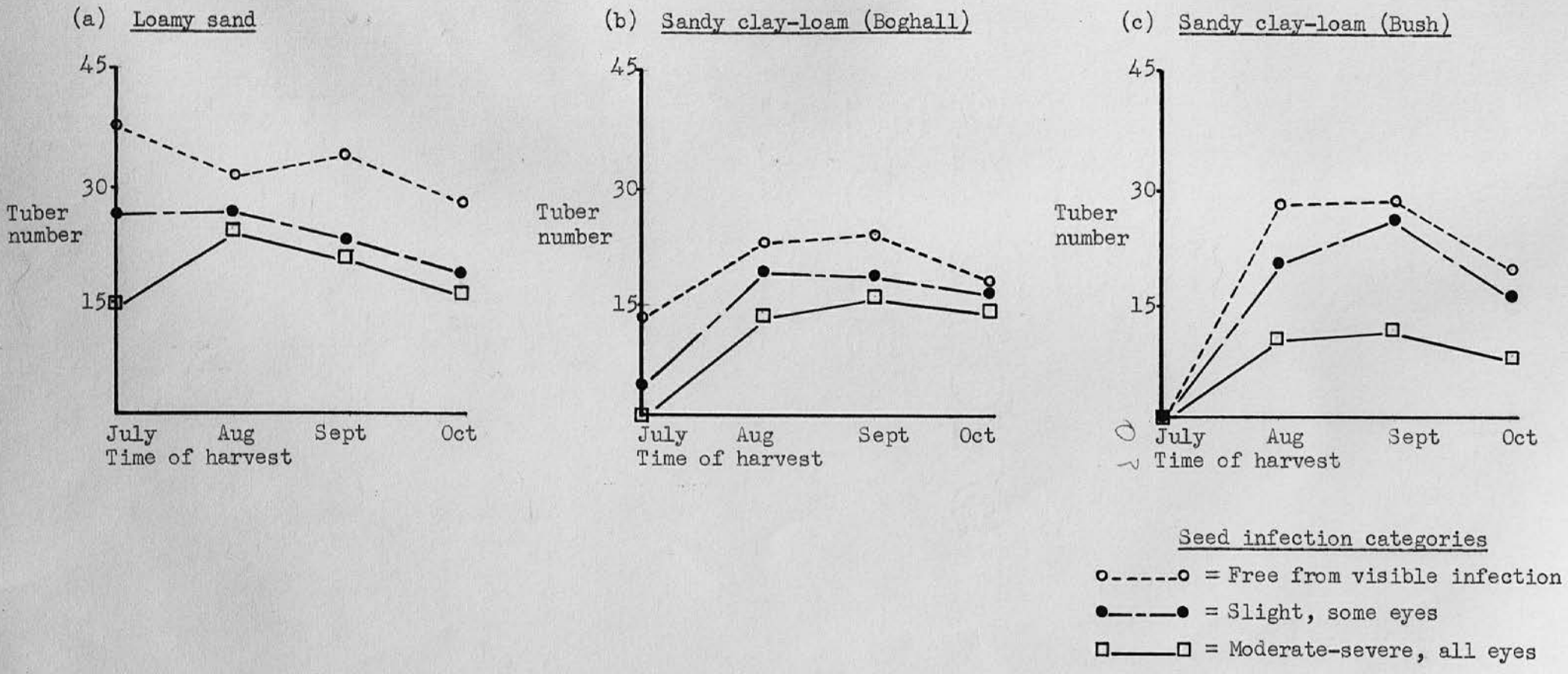
A = Free from visible infection

B = Slight, some eyes

C = Moderate-severe, all eyes

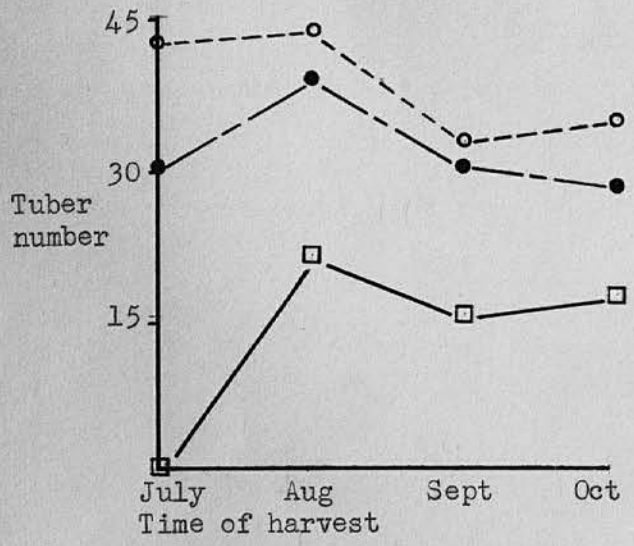
Fig. 2. Total tuber number per plant in relation to level of seed infection, time of harvest and soil type, 1968 and 1969.

1968

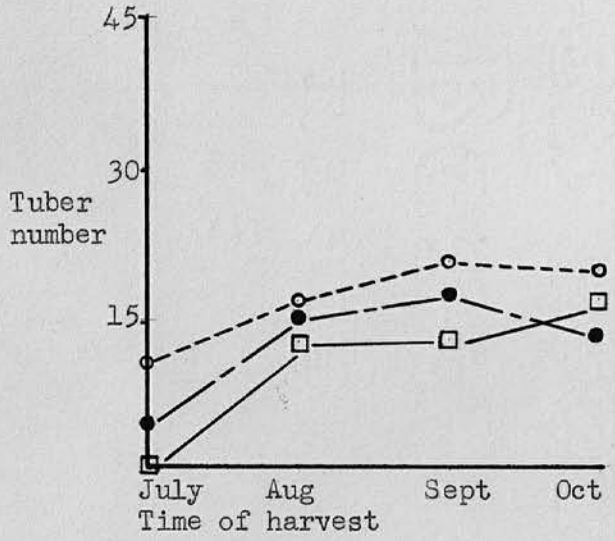


1969

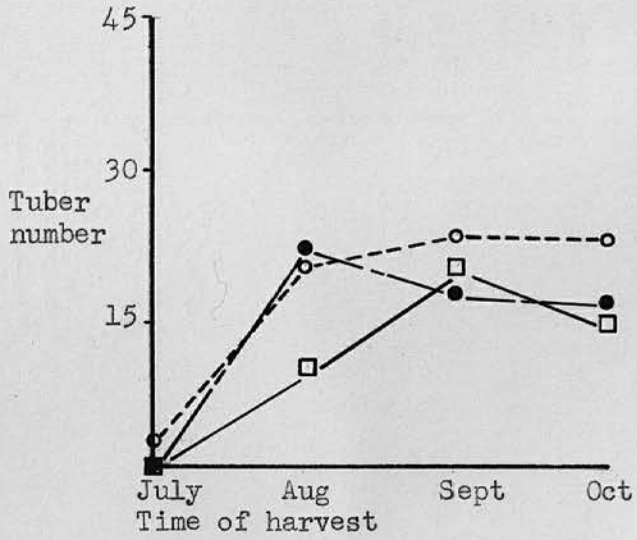
(d) Loamy sand



(e) Sandy clay-loam (Boghall)



(f) Sandy clay-loam (Bush)



Seed infection categories

o-----o = Free from visible infection

●—-—● = Slight, some eyes

□——□ = Moderate-severe, all eyes

Increased level of seed infection in all soils resulted in decreased total tuber number, at all times of lifting, the differences being usually most marked at the earlier harvest dates.

At all levels of seed infection, higher total tuber numbers were obtained from loamy sand than from either of the sandy clay-loam soils, where total numbers tended to be similar.

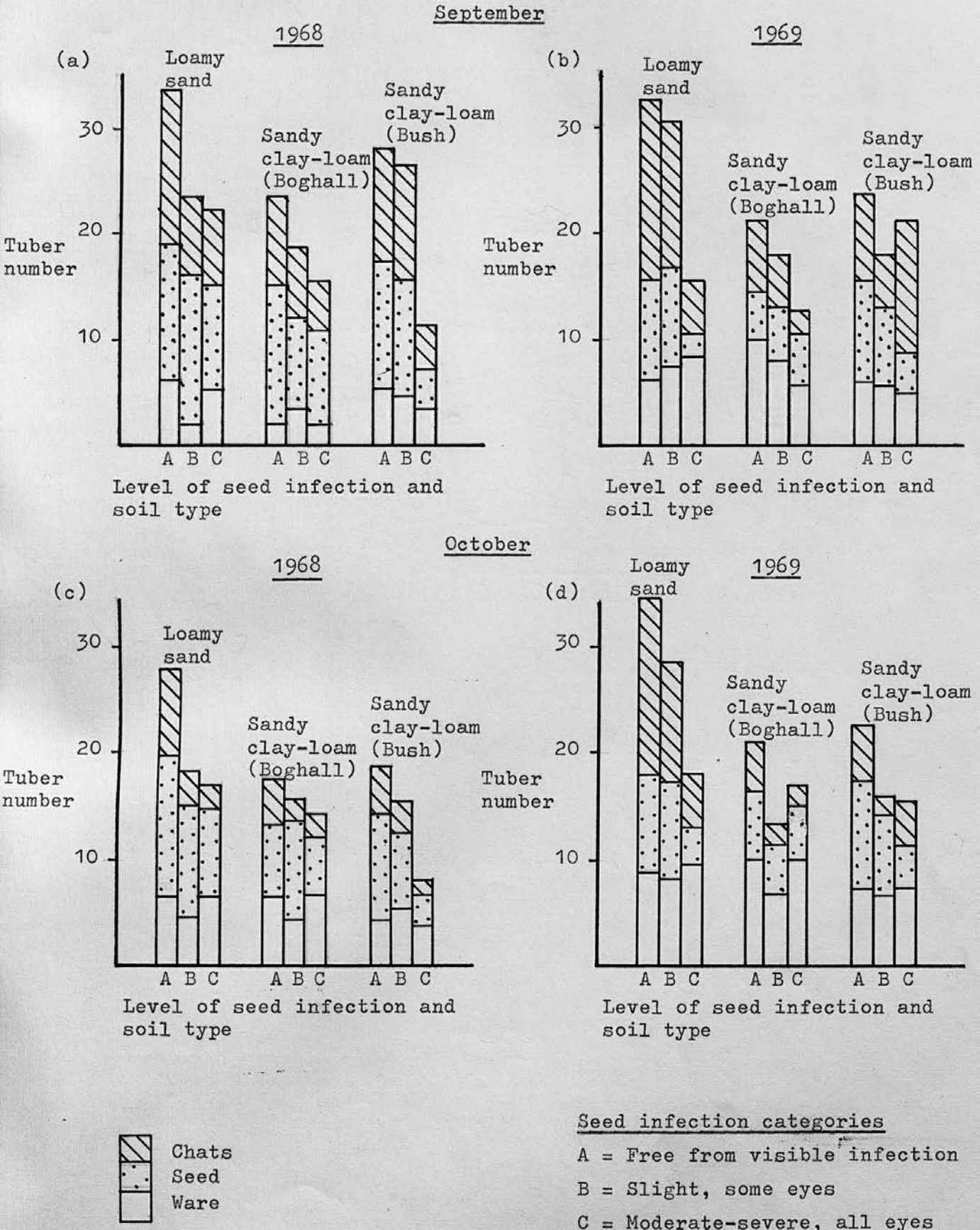
To show the effects of level of seed infection and soil type upon tuber numbers around the normal time of lifting, tuber numbers for ware, seed and chat fractions in September and October, 1968 and 1969, are shown in Fig. 3(a)-(d), (Appendix II (a), (b) and (c)).

The reduced total tuber numbers found with increased level of seed infection, were associated mainly with decreased seed and chat fractions. No consistent effect upon the ware fraction was found. Higher total numbers found with loamy sand in both years were again associated with higher seed and chat fractions.

4. Tuber weight yield. Data showing the effects of level of seed infection, time of harvest and soil type upon subsequent mean total tuber weight in 1968 and 1969 are shown in Fig. 4(a)-(f), (Appendix III(a), (b) and (c)).

Growth was found to continue longer in 1969 than in 1968 resulting, for all levels of seed infection in all soils, in higher final tuber yields. Reduced yields were associated with increased levels of seed infection at earlier lifting dates, but there was no significant effect of level of seed infection on final tuber yields. Similarly, higher tuber yields were found, at early lifts in both years, from loamy sand than from either

Fig. 3. Mean tuber number per plant in relation to level of seed infection and soil type, September and October, 1968 and 1969.



Seed infection categories

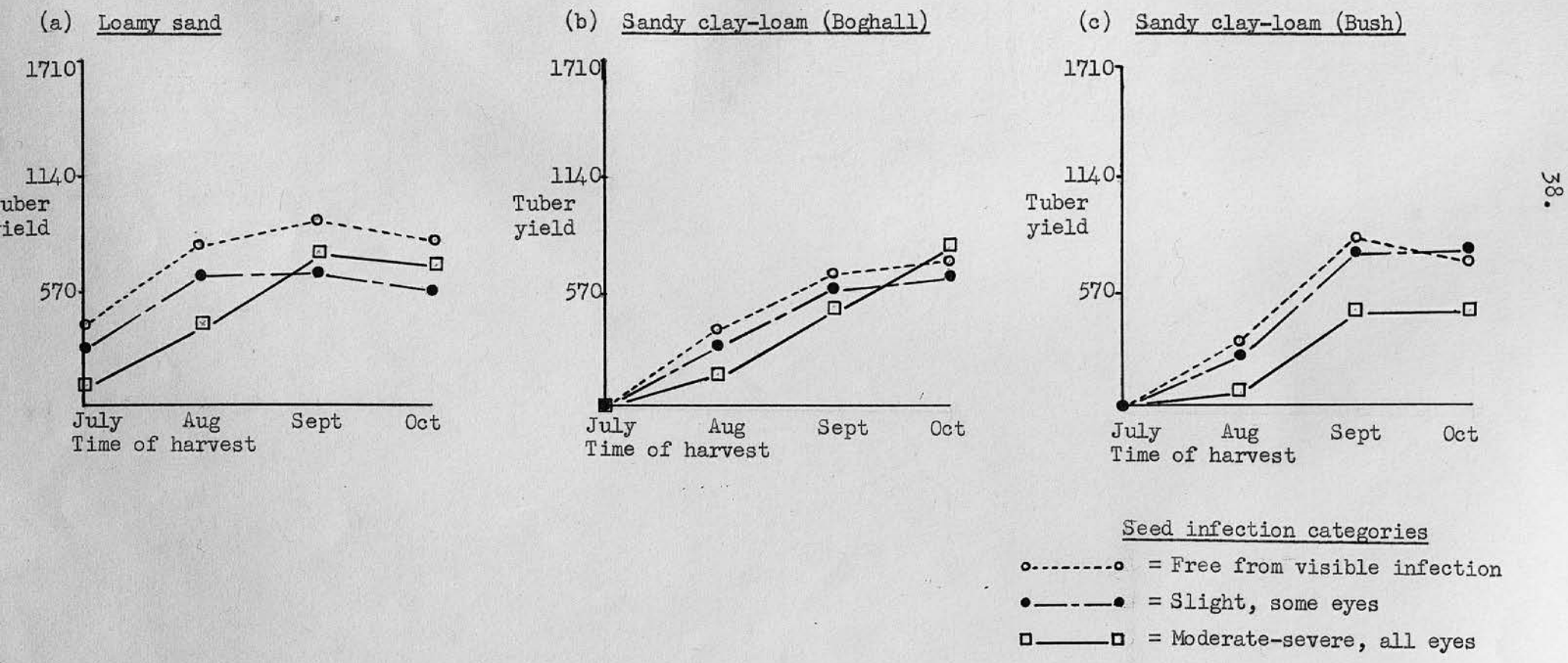
A = Free from visible infection

B = Slight, some eyes

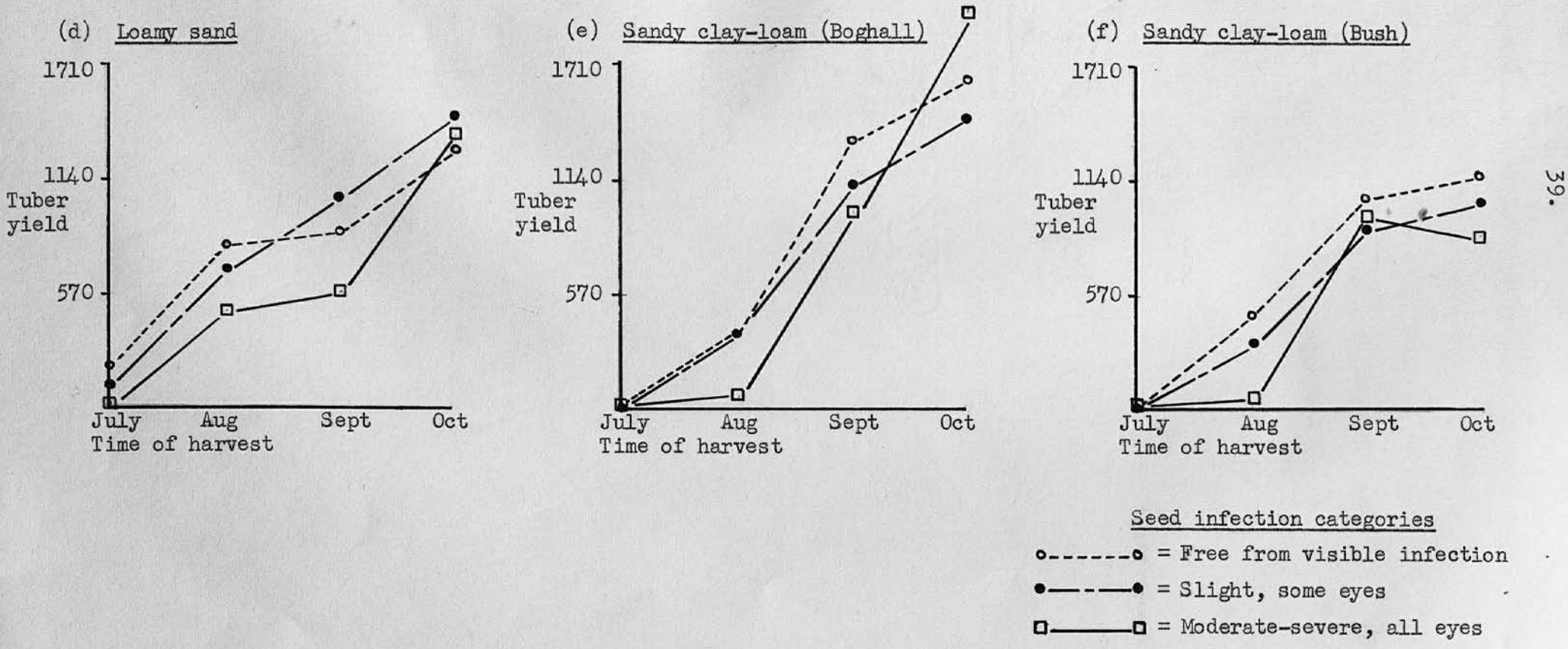
C = Moderate-severe, all eyes

Fig. 4. Mean total tuber weight (g.) per plant in relation to level of seed infection, time of harvest and soil type, 1968 and 1969.

1968



1969


(d) Loamy sand
1710
1140
570
Tuber yield
July
Aug
Sept
Oct
Time of harvest
(e) Sandy clay-loam (Boghall)
1710
1140
570
Tuber yield
July
Aug
Sept
Oct
Time of harvest
(f) Sandy clay-loam (Bush)
1710
1140
570
Tuber yield
July
Aug
Sept
Oct
Time of harvest
Seed infection categories
= Free from visible infection
= Slight, some eyes
= Moderate-severe, all eyes

of the sandy clay-loam soils but as lifting was delayed, there was no consistent effect of soil type upon final tuber yield.

Tuber yields of ware, seed and chat fractions in relation to level of seed infection and soil type from September and October lifts are shown in Fig. 5(a)-(d), (Appendix III(a), (b) and (c)).

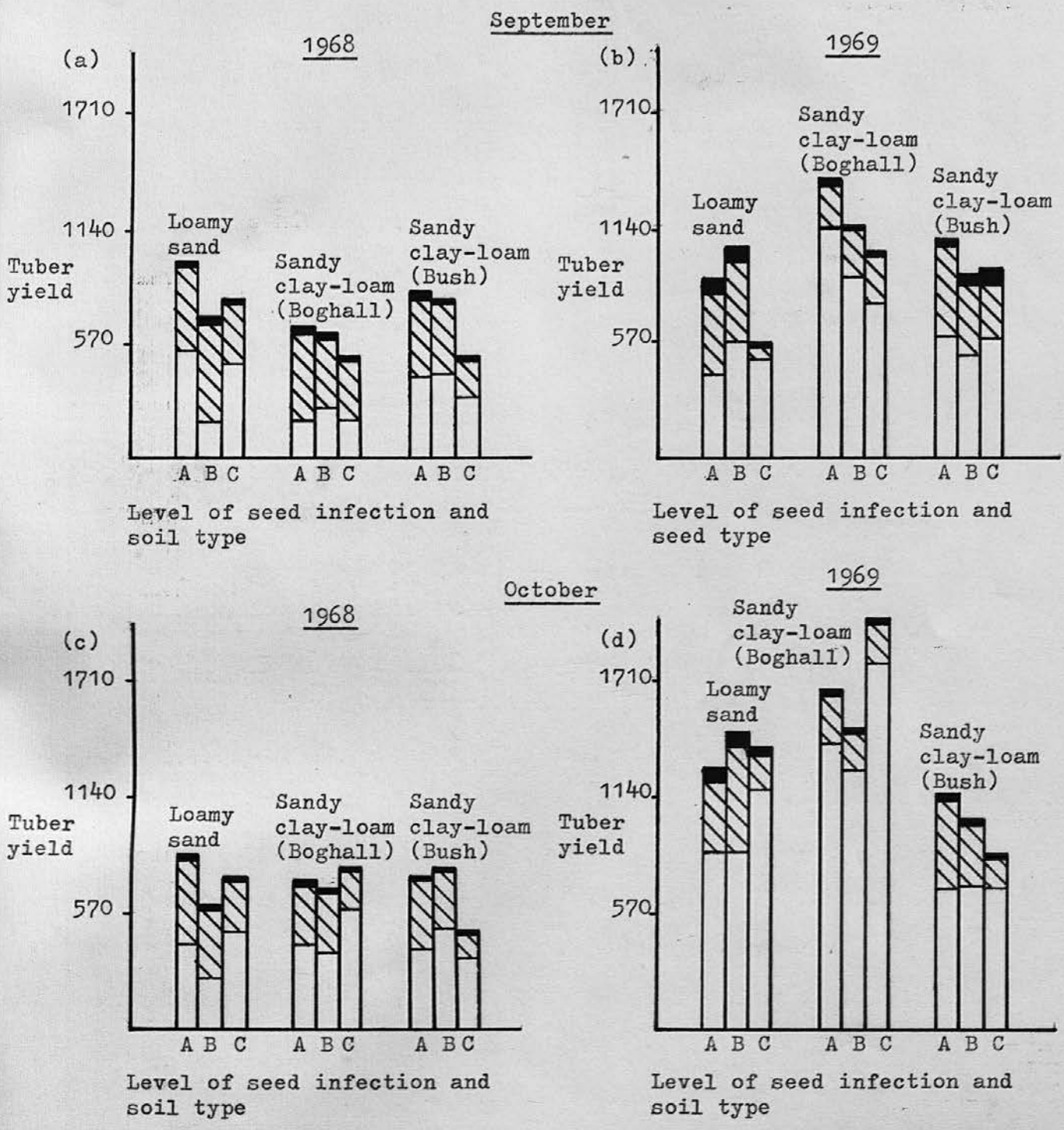
Increased final total yields, for all levels of seed infection in all soils, found in 1969, was the result of increased ware yields.

In all soils there was no significant effect of level of seed infection upon ware yields, but reduced seed yields were found from seed infected at all eyes, compared with the other seed infection categories, from September lifts in sandy clay-loam at Bush (1968), and loamy sand (1969) and from October lifts in the sandy clay-loams at Boghall in 1968 and at Bush in both years, and in loamy sand (1969). Chat yields were very occasionally significantly reduced with infection at all eyes.

5. Surface browning of underground stems and stolons. As shown by the data of Fig. 6(a)-(f), (Appendix IV(a), (b) and (c)), the percentage surface browning of stems and stolons, in relation to level of seed infection, time of harvest and soil type, was often greater in 1968 than in 1969, for early times of lifting. At later lifting dates, however, there were no marked differences found in the level of browning between years.

In both years, for all levels of seed infection in all soil types, the percentage browned surface area of stems and stolons increased as the season progressed. A higher proportion of the

Fig. 5. Tuber yield (g.) per plant, of ware, seed and chat fractions in relation to level of seed infection and soil type, September and October, 1968 and 1969.



Seed infection categories

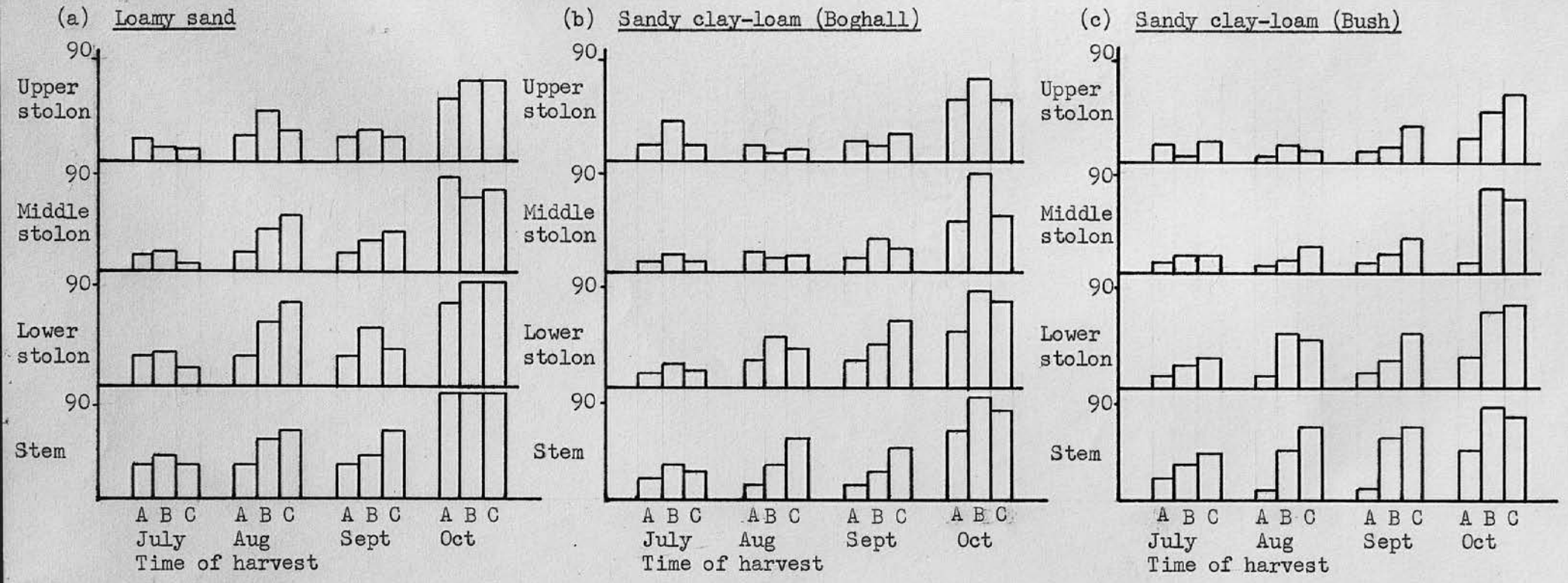
A = Free from visible infection

B = Slight, some eyes

C = Moderate-severe, all eyes

Fig. 6. Percentage surface browning of stems and stolons in relation to level of seed infection, time of harvest and soil type, 1968 and 1969.

1968

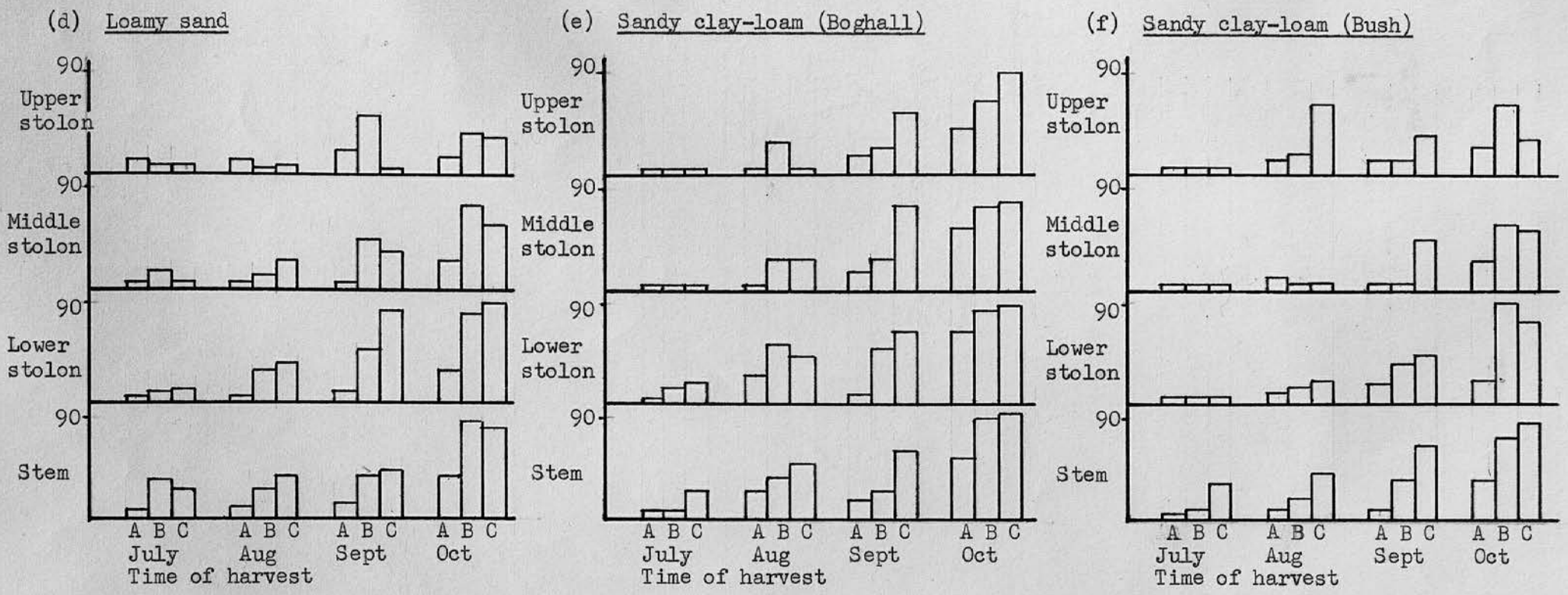


Seed infection categories

A = Free from visible infection

B = Slight, some eyes

C = Moderate-severe, all eyes



Seed infection categories

A = Free from visible infection

B = Slight, some eyes

C = Moderate-severe, all eyes

surface area of stems was affected by browning in comparison with stolons and the extent of stolon browning was usually found to vary according to position on the stems, the lower the point of insertion of the stolon upon the stem, the greater the percentage browning.

The results indicated that less stem and stolon browning was associated with the "free" seed infection category and that the extent of browning tended to increase with increase in level of seed infection.

Soil type had no consistent effect upon stem and stolon browning.

6. O. pustulans infection of underground stems and stolons.

From the assessments of stem and stolon surface area showing O. pustulans infection in relation to level of seed infection and soil type in 1968 and 1969, shown in Fig. 7-10 (Appendices V-VII), with each treatment, an index of total colonisation by O. pustulans was calculated by the addition of the percentage colonisation of the 12 portions of stems and stolons examined per plant. The indices are also shown in Fig. 7-10 in relation to level of seed infection and soil type and the averages for all dates of lifting are given in Table 4.

In general, stem and stolon infection was lower in 1969 than in 1968, presumably as a result of drier soil conditions occurring in 1969, but in both years, infection was established early and was found to increase as the growing season progressed. With late lifting, however, when the haulm was senescent or dead, most of the active colonisation had declined and assessments were

Figure 7 *Oospora pustulans* infection of underground stems and stolons in relation to level of seed infection and soil type, July 1968-69.

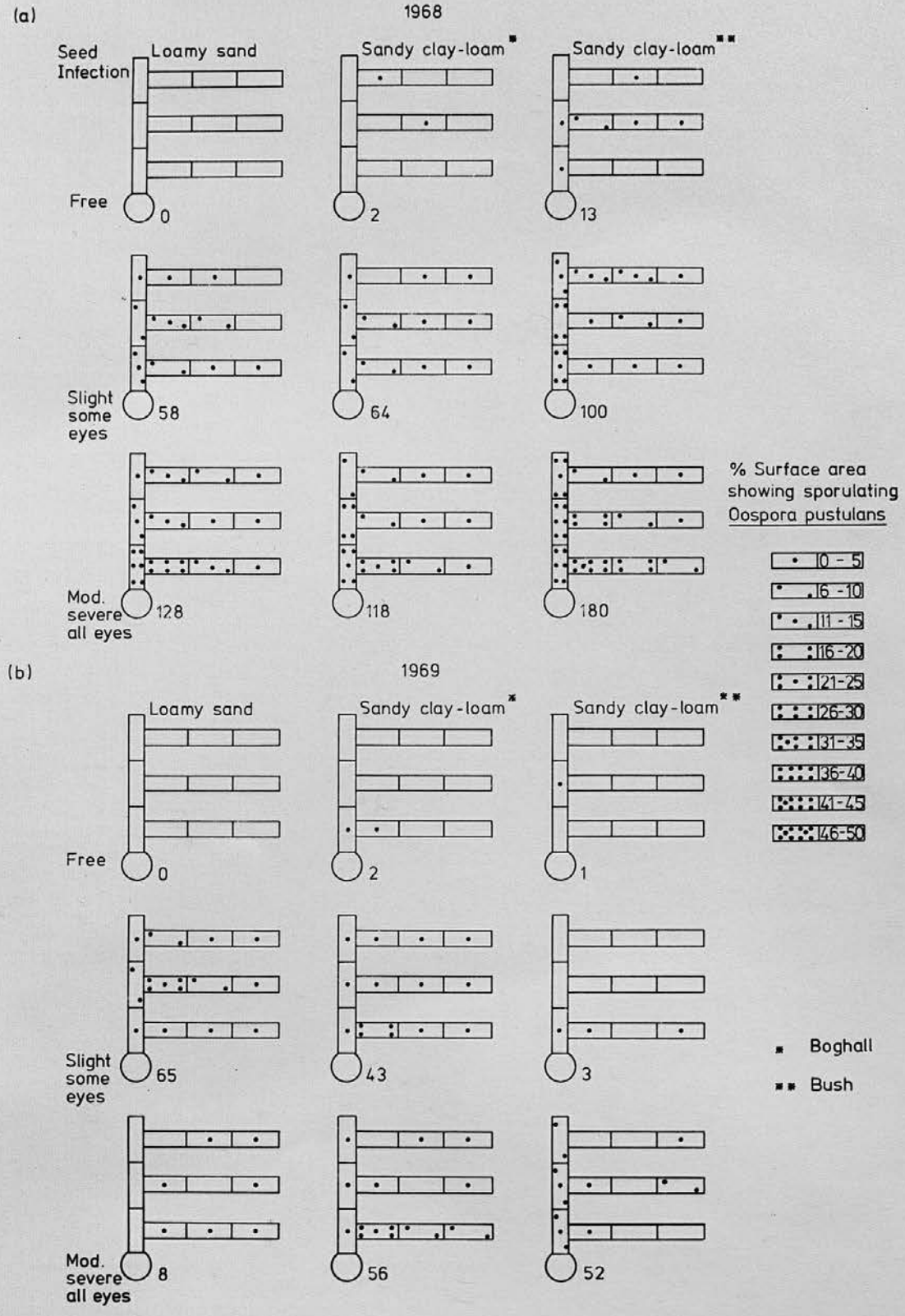


Figure 8 Oospora pustulans infection of underground stems and stolons in relation to level of seed infection and soil type, Aug. 1968-69.

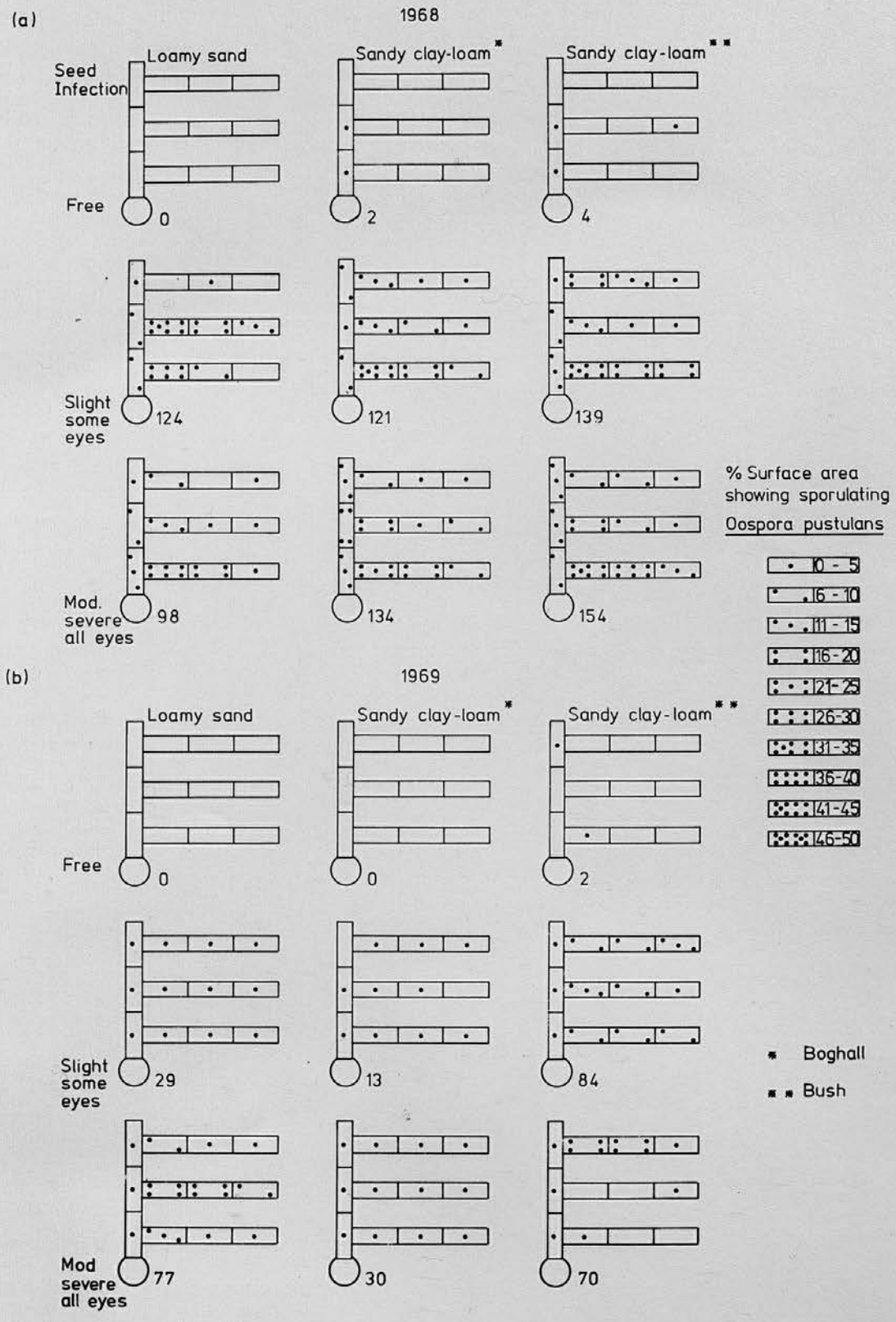


Figure 9 *Oospora pustulans* infection of underground stems and stolons in relation to level of seed infection and soil type, Sept. 1968-69.

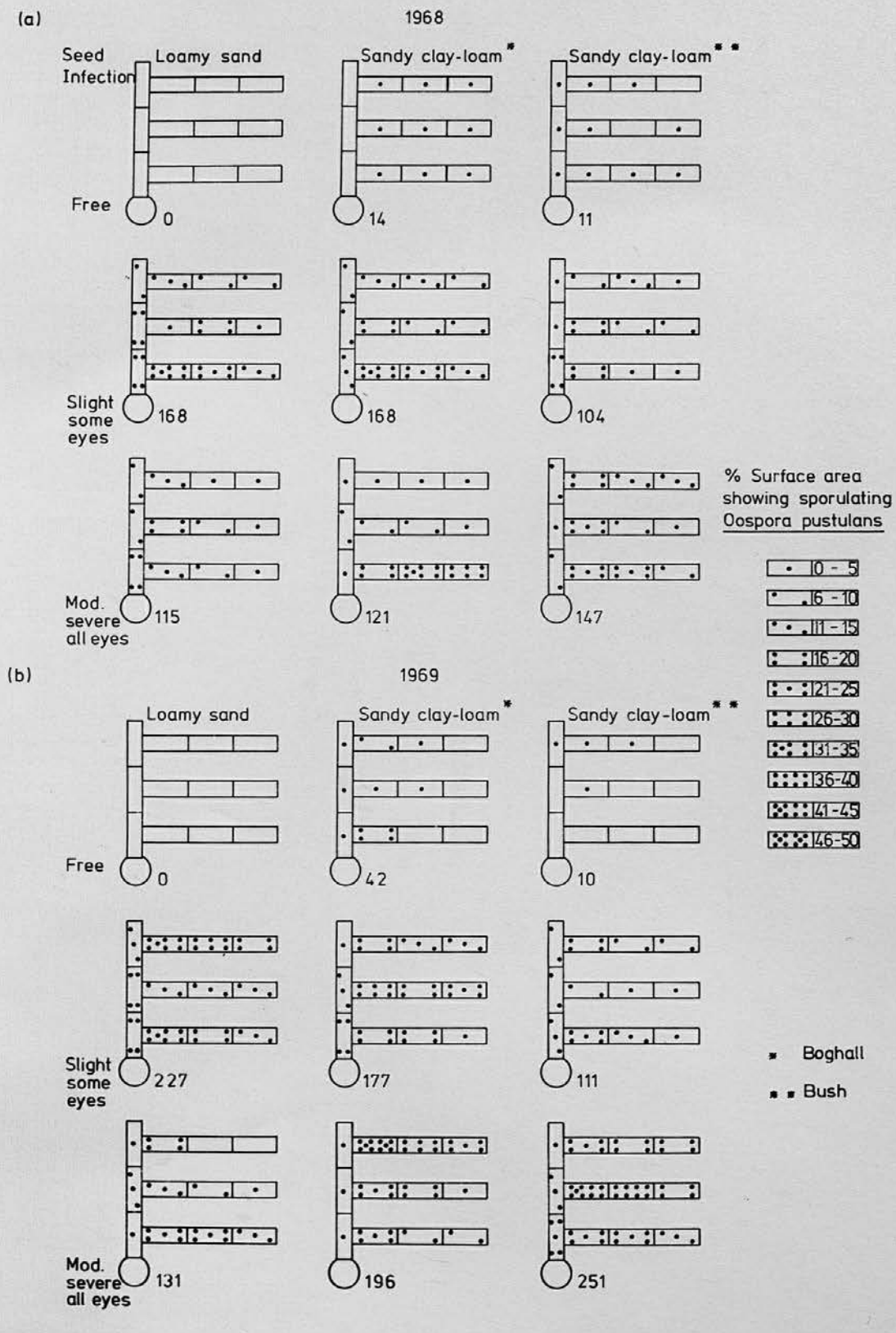
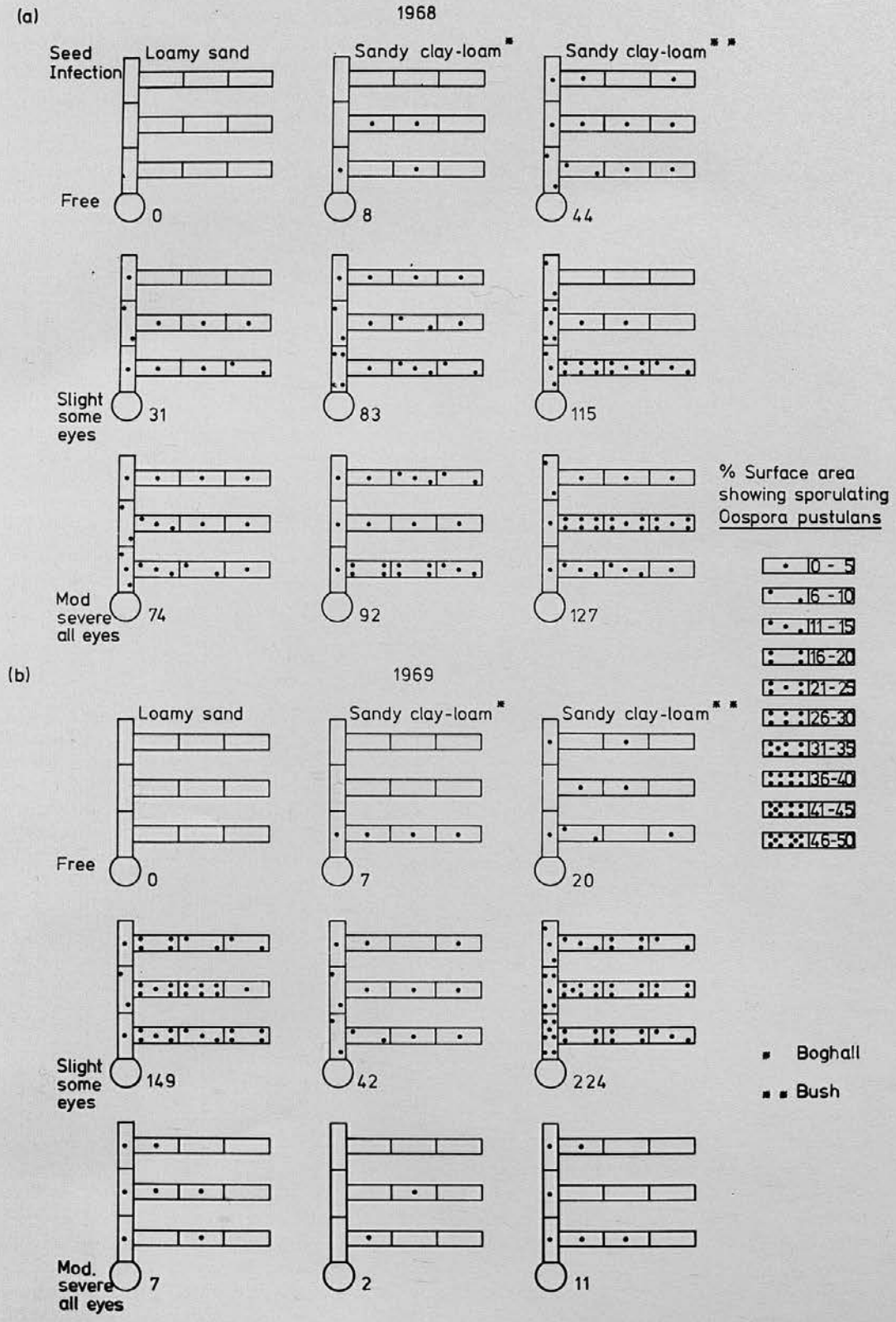


Figure 10 *Oospora pustulans* infection of underground stems and stolons in relation to level of seed infection and soil type, Oct. 1968-69.



confused by the influence of other causes of stem and stolon infection, chiefly Rhizoctonia solani, resulting in an apparent reduction in O. pustulans infection found upon plants harvested in October with some treatments.

In almost every treatment, the most extensive colonisation tended to be situated towards the lowest region of the stem and the proximal region of the stolons, i.e. nearest to the seed tuber, with colonisation also being greatest upon the lower stolons (Fig. 7-10). Increased level of seed infection gave an increase in the percentage colonisation of the stems and stolons, although in both years there was generally little difference between the two higher levels of seed infection.

The percentage colonisation of stems and stolons was least on the loamy sand and greatest on the heavier sandy clay-loam at Bush, except in the case of plants grown from the "Slight, some eyes" seed infection category in 1969.

Table 4. Index of O. pustulans colonisation of underground stems and stolons, in relation to level of seed infection and soil type, 1968 and 1969.

Soil type	Loamy sand		Sandy clay-loam (Boghall)		Sandy clay-loam (Bush)		Mean	
Seed infection	1968	1969	1968	1969	1968	1969	1968	1969
Free, no eyes	0	0	7	13	18	8	8	7
Slight, some eyes	95	118	104	69	115	106	104	98
Moderate-severe, all eyes	104	56	116	71	150	96	123	74
Mean	66	58	75	51	95	70	-	-

7. Skin spot infection of the subsequent crop. The results of assessments of skin spot infection of progeny tubers after tray storage at 4°C (Table 5), show that in neither year was skin spot infection high.

In both years, for all soils, increase in level of seed infection resulted in higher incidence of skin spot infection but, as with O. pustulans colonisation of stems and stolons, this effect was most evident in comparing "free" seed with the other seed infection categories. Although no O. pustulans infection was detected in either year upon stems or stolons grown from "free" seed in loamy sand, the tubers from these plants did show some very slight skin spot infection.

In 1968, higher levels of skin spot infection occurred in the sandy clay-loam soils, than in the loamy sand but in 1969, infection levels in loamy sand and in the Boghall sandy clay-loam soil were similar, and the lowest skin spot infection was found associated with Bush sandy clay-loam soil.

Table 5. Skin spot infection of the subsequent crop in relation to level of seed infection and soil type, 1968 and 1969.

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Seed infection	S.I.I. 1968	S.I.I. 1969	E.I.I. 1968	E.I.I. 1969	S.I.I. 1968	S.I.I. 1969	E.I.I. 1968	E.I.I. 1969	S.I.I. 1968	S.I.I. 1969	E.I.I. 1968	E.I.I. 1969
Free, no eyes	0.2	0.1	1.2	0.4	0.9	0.4	8.5	5.7	3.9	0.3	35.4	7.9
Slight, some eyes	2.1	4.7	15.4	32.5	6.6	3.9	54.2	28.8	7.6	1.5	62.5	18.6
Moderate-severe, all eyes	2.3	6.9	20.0	76.5	6.3	5.0	50.0	36.8	*	1.1	*	13.3

*Insufficient progeny tubers were available to provide an adequate sample for assessment.

8. Skin spot infection and O. pustulans eye infection of subsequent crop after storage. Assessments of skin spot infection and O. pustulans eye infection of progeny tubers in relation to level of seed infection and soil type after different storage treatments (Tables 6 and 7), show that in almost every treatment, increase in level of seed infection resulted in increased subsequent skin spot development and O. pustulans eye infection of progeny tubers. This was particularly so with low temperature and high humidity storage but with other treatments, although differences in levels of subsequent infection were less obvious, infection still tended to increase with increasing level of seed infection. Under most conditions of storage and for most levels of seed infection, there was a tendency for lower levels of subsequent skin spot infection, particularly of eye infection, to be associated with tubers grown in the lighter soil.

Storage in conditions of high humidity, of tubers grown from seed of all levels of infection in all soils, increased the level of severity of skin spot infection and the prevalence of O. pustulans on tubers, compared with storage in dry conditions. Storage at 10°C until March, gave lower skin spot surface infection indices of all treatments from visual assessments, compared with storage at 3°C until June, but gave more eye-cores showing infection by O. pustulans from microscopic assessments.

Discussion

Skin spot infection of seed tubers is known to cause delayed emergence and emergence failure, particularly in the variety King Edward. These effects were again observed in this

Table 6. Skin spot surface infection index in relation to level of seed infection, soil type and storage treatment.

1969-70

Soil and storage treatment / Seed infection	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
	3°C Humidity		10°C Humidity		3°C Humidity		10°C Humidity		3°C Humidity		10°C Humidity	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Lo
Free, no eyes	0.1	0.0	0.1	0.1	2.9	0.7	2.0	0.2	2.8	0.2	0.4	0.
Slight, some eyes	17.0	3.2	4.1	0.9	17.7	1.8	5.3	1.0	8.7	2.1	5.2	0.
Moderate-severe, all eyes	21.2	4.8	2.1	0.5	29.6	4.4	7.7	3.4	11.8	2.7	8.0	1.

Table 7. Skin spot eye infection - % eye-cores infected by O. pustulans in relation to level of seed infection, soil type and subsequent storage treatment.

1969-70

Soil and storage treatment / Seed infection	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
	3°C Humidity		10°C Humidity		3°C Humidity		10°C Humidity		3°C Humidity		10°C Humidity	
	High	Low	High	Low	High	Low	High	Low	High	Low	High	Lo
Free, no eyes	0.0	0.0	4.2	0.0	18.5	3.8	43.5	11.2	7.6	0.8	36.9	0.
Slight, some eyes	47.1	38.1	68.7	14.7	51.9	16.8	58.5	21.9	47.2	14.9	77.1	22.
Moderate-severe, all eyes	51.8	51.6	63.1	17.5	80.5	43.8	93.0	56.3	43.1	30.6	84.1	24.

3°C - Assessed June, 1970.

10°C - Assessed March, 1970.

investigation. Increased level of seed infection also caused a reduction in numbers of main stems produced from the seed tuber, although some compensatory growth in the form of greater lateral stem production occurred with more heavily infected seed. However, fewer tubers were produced with increased levels of seed infection (Fig. 2 and 3): Toosey (1964), has indicated that with comparable presprouting treatments the number of tubers produced increases in direct proportion to the number of main stems. Differences in total tuber weight yields were evident only in the early part of the growing season (Fig. 4 and 5), but final seed yields were adversely affected by increasing levels of seed infection. As also shown by Salt (1958) and Boyd and Lennard (1961a), this lower seed yield was offset by higher ware yield so that final total yields were less affected.

Evidence was also obtained that the type of soil can play an important part in influencing the rate of emergence and subsequent yield after planting infected seed. The quicker plant emergence, found in loamy sand, from all levels of seed infection (Table 3), was accompanied by increased tuber numbers and, at early lifting, greater tuber weight yields (Fig. 2-5). This was probably due to higher temperatures which are usually associated with lighter soils and which, by promoting more rapid extension growth, help to overcome the effects of the disease.

The level of infection of the seed tubers was shown to influence the severity of the disease on the progeny tubers. Transmission, however, was not directly proportional to the inoculum provided by the seed tubers. This can be seen in Table 5, where the more severely affected seed is little more

effective in transmission than the slightly affected seed, and can be seen again when the surface browning and progress of O. pustulans infection on underground stems and stolons is considered (Fig. 6 and Table 4).

Most surface browning and colonisation by O. pustulans tended to occur upon the lower region of the stems and upon the lower stolons (Fig. 6-10). This would indicate the seed tubers to be the main source of infection and that, although no test for the presence of O. pustulans was made with any of the soils used, if any soil contamination had been present, the level was insufficient to obscure the influence of seed infection.

The extent of O. pustulans infection of stems and stolons was influenced by soil type, and was generally lower in loamy sand than in heavier soils (Table 4, Fig. 7-10). The level of transmission of skin spot to progeny tubers was also affected by soil type, particularly with regard to eye infection. For example, in 1968, from seed tubers in the "free" infection category, the eye infection index of tubers in loamy sand was 1.2, whereas in Bush sandy clay-loam soil, the corresponding figure was 35.4: in the Boghall sandy clay-loam, which differed from that of Bush in having a higher proportion of stones >2 mm., the index was 8.5 (Table 5). It is possible that in lighter soils, transmission is discouraged by a higher degree of aeration and lower moisture retention.

Although the influence of seed infection level and soil type upon disease in the crop was still evident after storage, the level of severity of symptoms was considerably modified by varying storage conditions. Dry conditions gave much less skin

spot than humid conditions and low temperatures greatly aggravated symptom development (Table 6). The percentage of eye-cores showing infection was also reduced in dry conditions but more infection was found after storage at 10°C than after storage at 3°C (Table 7).

A_2 The effect of level of seed infection and O. pustulans inoculum in sterilised and unsterilised soils upon O. pustulans infection of underground stems and stolons.

This experiment was designed to investigate the effect of skin spot infection of seed tubers and inoculation of soil with O. pustulans, using different sterilised and unsterilised soils, upon the level of O. pustulans infection of underground stem and stolon growth.

Materials and Methods

In early June, 1970, samples of loamy sand and sandy clay-loam soils were (a) flame sterilised, (b) left unsterilised and placed in polythene bags (45 x 60 cm.), at the rate of approximately 18 litres per bag. Details of mechanical analyses of soils are shown on Page 25. The soils were then either inoculated with a spore suspension of O. pustulans at the rate of 700 $cm.^3$ per bag (10^5 spores per $cm.^3$), applied through a wide nozzle hand-sprayer or left uninoculated. On 15 June, one King Edward seed tuber was planted in each bag, using two seed tuber infection categories:- "free-trace" and no eye infection or "slight" with some eye infection. The bags were then sunk into field soil at Easter Howgate farm, Midlothian, in a split-plot design of six replicates per treatment, with two different times of lifting forming sub-plots. Guard rows of King Edward seed tubers were then planted around and between each sub-plot. Three replicates from each treatment were harvested on 19 August and the remaining three, on 10 September, 1970. One main stem with three attached

stolons was then selected per replicate and after washing and incubation treatment, as in Experiment A_1, assessed for *O. pustulans* infection.

Results

For each plant assessed for *O. pustulans* infection, an index of total colonisation was calculated by adding the percentage surface areas showing infection of the 12 parts examined in each plant per treatment. Indices for all treatments, averaged for both dates of harvest, are shown in Table 7 (Appendices VIII-X).

In general, more *O. pustulans* infection of underground stems and stolons occurred from seed planted with the higher level of skin spot infection. Greater infection was also generally found associated with sterilised, compared with unsterilised soils, but there was no consistent effect of either soil inoculation or of soil type upon *O. pustulans* colonisation of stems and stolons. In most treatments, infection tended to be greater towards the lower region of the stem and the proximal region of the stolons, i.e. nearest to the seed tuber, with infection also tending to be greater upon the lower stolons (Appendices VIII-X).

Discussion

As in Experiment A_1, the higher level of seed infection category gave more infection by *O. pustulans* of stems and stolons. Colonisation was affected, in most cases, by soil sterilisation: increased colonisation from sterilised, compared with unsterilised soils, presumably, was the result of lack of competition from other soil organisms which may have adversely affected the activity of *O. pustulans*. Soil inoculation had no consistent

effect upon infection and it was observed that the pattern of colonisation of stems and stolons, in general, followed that of Experiment A_1, i.e. colonisation was concentrated towards the seed tuber. Thus, even where soil inoculum may have increased the total colonisation of stems and stolons by O. pustulans, it was insufficient to overcome the influence of seed infection. There was no consistent effect of soil type upon O. pustulans infection of stems and stolons although in Experiment A_1, higher levels of infection were found with heavy clay, compared with light, sandy soils.

Table 7. Indices of total colonisation by O. pustulans of underground stems and stolons, in different sterilised and unsterilised soils, in relation to level of seed infection and soil inoculum of O. pustulans.

Soil type		Loamy sand		Sandy clay-loam (Boghall)		Sandy clay-loam (Bush)		Mean ± 8.1
Steri-lisation	Inoculation	Free	Slight, some eyes	Free	Slight, some eyes	Free	Slight, some eyes	
Unsteri-lised	Uninoculated	22.5	115.4	3.4	26.2	10.0	20.5	33.0
	Inoculated	14.2	17.9	5.0	24.2	9.2	71.7	23.7
Steri-lised	Uninoculated	2.5	30.0	69.2	76.7	12.5	83.0	45.6
	Inoculated	0.9	50.4	44.2	26.7	28.3	195.9	57.7
Mean ± 10.0		10.0	53.4	30.4	38.4	15.0	92.7	

SE for body of table = ± 19.9

A_3 The overwintering of O. pustulans in different soils.

This experiment was designed to study the extent of overwintering of O. pustulans in various soils and to investigate any effect which soil sterilisation or presence of organic matter may have upon the level of survival.

Materials and Methods

On 20 December, 1968, 600 g. samples of sterilised and unsterilised loamy sand and sandy clay-loam soils, to which (a) 12 g. sterilised, senescent, above-ground potato stems were added or (b) no potato stems were added, were each inoculated with a spore suspension of O. pustulans (20 $cm.^3$ x 10^7 spores per $cm.^3$), and placed in sealed glass bottles, using four replicates per soil treatment. Details of mechanical analyses of soils are shown on page 25. Soil sterilisation was carried out, using a 3 kilowatt electric steriliser for two hours and the potato stems were sterilised in a steam autoclave at a pressure of 15 lb. per sq. in. for 30 minutes. All treatments were stored in an insulated shed and one replicate per treatment was removed on each of the following dates:- 23 July; 14 November, 1969 and 24 June and 2 September, 1970. The soil from each replicate was then assessed for the presence of O. pustulans, using tomato seedlings as indicator plants (Hirst and Salt, 1956). Each soil treatment was mixed thoroughly with an equal volume of sterilised sand and placed in four $3\frac{1}{2}$ in. (8.75 cm.), diameter clay pots. Five tomato seeds (cv. "Ailsa Craig"), were then sown in each pot, and grown on at 15°C, in a glasshouse, for seven weeks. All plants were then removed from the soils,

washed, and the stems and lateral roots discarded. After surface disinfection, by dipping for one minute in a 1:20 solution of Deosan, each root was rinsed in distilled water for one minute and placed on moist paper in small plastic boxes and incubated for five days at 15°C. After incubation, all roots were examined microscopically and assessed for percentage upper surface area showing sporulating O. pustulans.

Results

Assessments of colonisation of tomato roots by O. pustulans are shown in Table 8.

Table 8. Percentage upper surface area of tomato roots infected with O. pustulans, at different dates of sampling, in relation to sterilisation of different soils and presence of senescent, potato stems.

Soil type	Date of Sampling	Sterilised soil		Unsterilised soil	
		Stems present	Stems absent	Stems present	Stems absent
Loamy sand	23 July 1969	9.6	2.9	0.0	0.0
	14 Nov 1969	2.1	3.6	0.0	0.0
	24 June 1970	4.1	3.4	0.0	0.0
	2 Sept 1970	3.1	3.2	0.1	0.0
Sandy clay-loam (Boghall)	23 July 1969	0.5	0.3	0.5	0.2
	14 Nov 1969	8.3	1.8	0.4	0.0
	24 June 1970	2.6	0.0	1.7	0.0
	2 Sept 1970	0.0	0.0	0.0	0.0
Sandy clay-loam (Bush)	23 July 1969	3.7	7.0	0.1	0.1
	14 Nov 1969	28.4	37.2	1.6	1.1
	24 June 1970	12.8	16.7	0.0	0.2
	2 Sept 1970	6.4	0.1	0.0	0.0

More root infection was found from soils sterilised before inoculation than from unsterilised soils, particularly with the Bush sandy clay-loam soil sampled in November, 1969 and June, 1970. Infection in sterilised soil, with the exception of sterilised loamy sand, was found to increase in November, 1969 and thereafter decrease until September, 1970. Infection in loamy sand, however, remained more or less constant, apart from the high infection rate in July, 1969, where stems were present. Extremely low levels of root infection were found at all times of sampling, in unsterilised soil, with samples often giving no infection. Soil type had no effect upon infection in unsterilised soils but with sterilised soil, infection in Bush sandy clay-loam was markedly higher than in the other soils. The presence of senescent potato stems had no consistent effect upon subsequent root infection. With sterilised soils, infection was detected from all samples, 11 months after inoculation, and in four of the six samples, 21 months after inoculation: with unsterilised soils, three of the six samples showed infection, 11 months after inoculation, and only one of the six samples showed infection after 21 months.

Discussion

The results, in keeping with the observations of Hirst et al (1970), suggest that there is no growth of O. pustulans in normal field soils, in the absence of susceptible host plants. Only one of the six unsterilised soils showed infection 21 months after inoculation, indicating only a limited ability of the fungus to survive. There is, however, evidence (Hirst et al, 1970), that O. pustulans can persist in the form of

microsclerotia, through rotations in ware and even seed growing areas. A greater level of infection, and infection over a longer period, was found with sterilised, compared with unsterilised soils, presumably due to the absence of competitive effects from other soil micro-organisms: the presence of other soil organisms in unsterilised soils, may have influenced the ability of O. pustulans to survive but may also have influenced, more directly, the active colonisation of roots, as indicated by Experiment A_2. Soil type influenced the level of infection of tomato roots, to a marked extent, in sterilised soils but this again may have been due to conditions influencing colonisation of roots, rather than to conditions affecting the survival of the fungus. There was no evidence of an influence of soil type in unsterilised soils.

A_4 The effect of varying levels of soil moisture during growth upon skin spot development of the subsequent crop.

The aim of the experiment was to determine the effect of varying amounts of water applied to the soil during the later stages of crop growth upon the amount of skin spot development.

Materials and methods

Individual polythene bags (500 gauge, 45 cm. wide x 60 cm. deep), in which 12, 3/8 in. (0.9 cm.), drainage holes had previously been pierced, were filled with 18 litres of flame sterilised, loam soil. Seed size King Edward tubers, showing "slight" surface and some eye skin spot infection, were planted 3-4 in. (7.5-10.0 cm.), deep, one tuber per bag on 1 June, 1970. The bags were set into field soil at Bush Estate, Midlothian, arranged in four blocks of 16 bags, so that the level of the soil within the bags coincided with that of the soil outside of them. The sides of the bags were rolled down almost to ground level. To enable strict control to be made over the soil moisture available to each bag, the entire experiment was placed under a polythene cover (1000 gauge), supported on a wooden frame, extending to 32 ft. x 12 ft. (9.6 m. x 3.6 m.), set at 6 ft. (1.8 m.), above ground level. Weekly watering of all blocks was carried out during the period from 26 June to 14 August, 1970, 0.5 litres water being applied to each bag. Over the period 21 August to 2 October, the 16 bags within each block were each subjected to different watering treatments, arranged in two series, as shown in Fig. 11.

Fig. 11. Watering treatments over period 21 August to 2 October, 1970.

Series A

Dates of applying 1 in. of water	1	2	3	4	5	6	7	8
21 Aug	+							
28 Aug	+	+						
4 Sept	+	+	+					
11 Sept	+	+	+	+				
18 Sept	+	+	+	+	+			
25 Sept	+	+	+	+	+	+		
2 Oct	+	+	+	+	+	+	+	
Total water applied ($cm.^3$ per bag).	9030	7740	6450	5160	3870	2580	1290	0
Rainfall equivalent (in.)	7	6	5	4	3	2	1	0

Water treatments

Series B

Dates of applying 1 in. of water	9	10	11	12	13	14	15	16
21 Aug	+	+	+	+	+	+	+	
28 Aug	+	+	+	+	+	+		
4 Sept	+	+	+	+	+			
11 Sept	+	+	+	+				
18 Sept	+	+	+					
25 Sept	+	+						
2 Oct	+							
Total water applied ($cm.^3$ per bag).	9030	7740	6450	5160	3870	2580	1290	0
Rainfall equivalent (in.)	7	6	5	4	3	2	1	0

Water treatments

Dates of applying 1 in. of water

+ 1290 $cm.^3$ water applied, equivalent to 1 in. of rain.

The produce from all treatments was lifted on 12 October, 1970, placed in net bags and clamped until April, 1971 when the tubers were removed, washed and assessed for skin spot development.

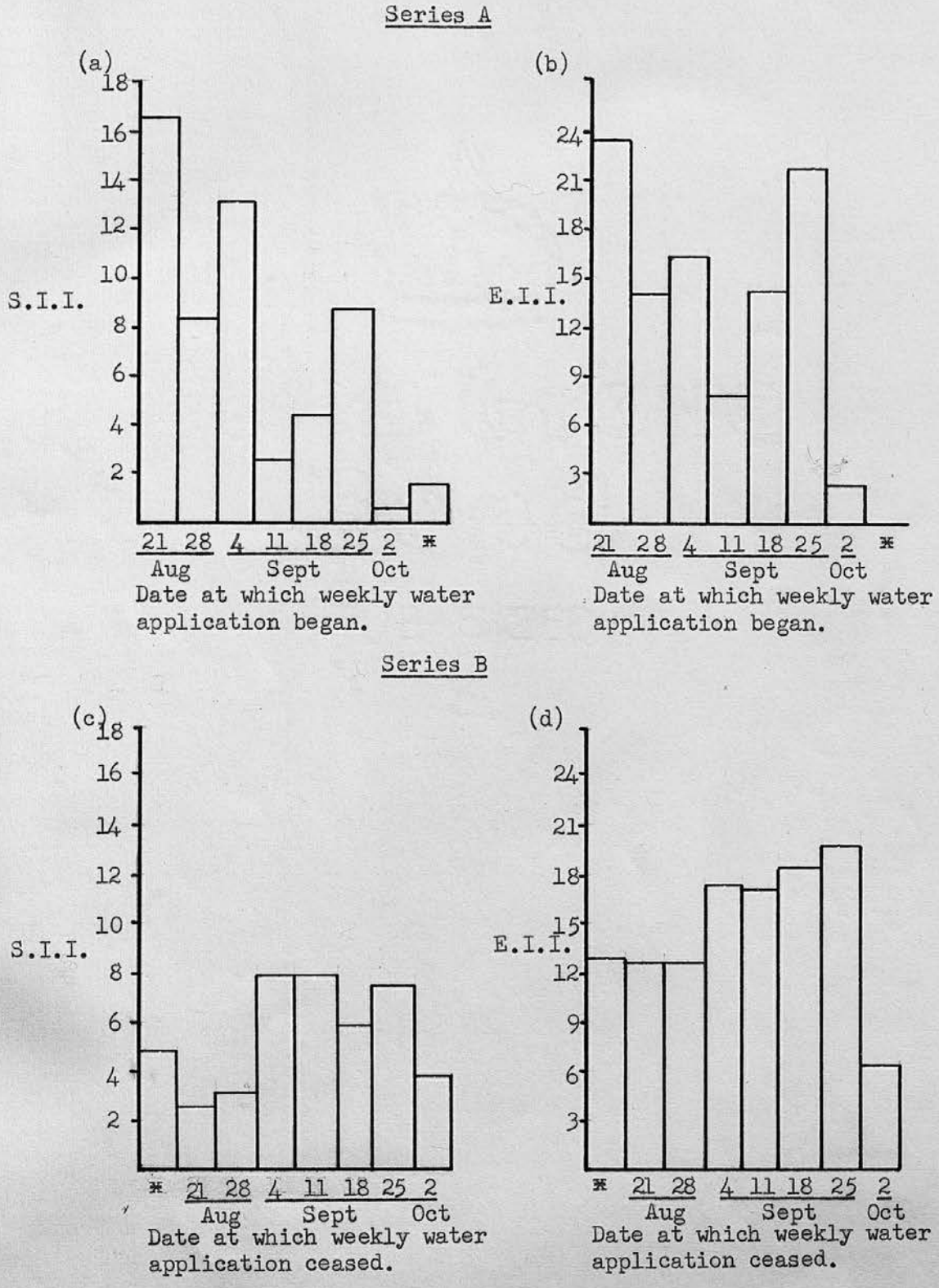
Results

With both series of treatments, higher levels of surface skin spot infection tended to occur the greater the number of weeks water was applied (Fig. 12(a) and (c)), (Appendix XI). This trend was more evident where water was withheld for varying periods during the early part of the experimental period. Eye infection showed a similar trend in relation to the application and withholding of water (Fig. 12(b) and (d)), (Appendix XI), although maximum level of infection tended to occur with less total water applied, than with surface infection. In considering the two series, the results were often inconsistent and there was no conclusive evidence that the time when water was applied, from August to October, had any marked significance in relation to the severity of symptoms developed upon the tubers. When surface and eye infection indices, for samples from treatments receiving the same total amount of water, were averaged (Fig. 13), (Appendix XII), surface infection and eye infection increased with increasing rates of water application up to the equivalent of 5 in. and 2 in. of rainfall respectively.

Discussion

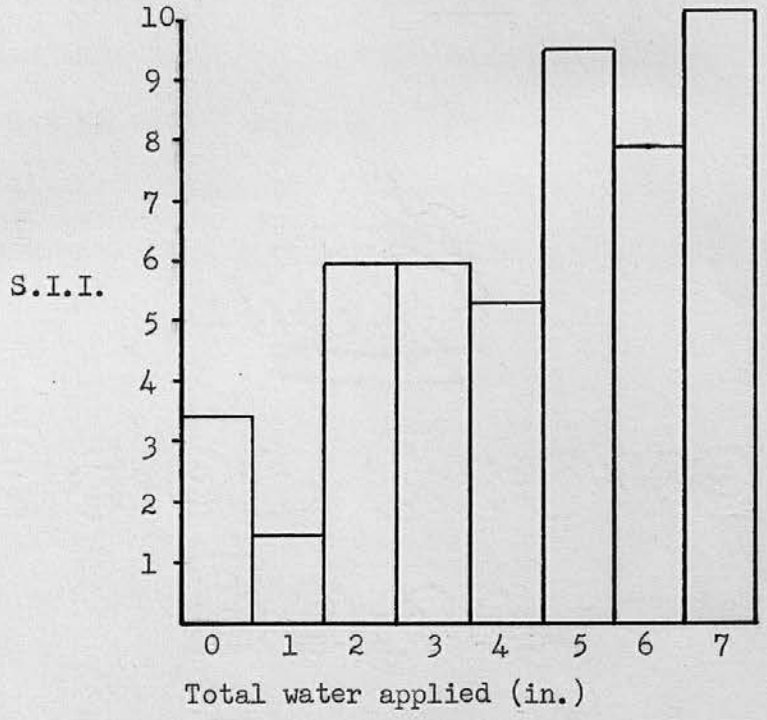
The finding from this investigation, that more skin spot infection of tubers was obtained with increased amount of water applied during August to October, supports the observation of

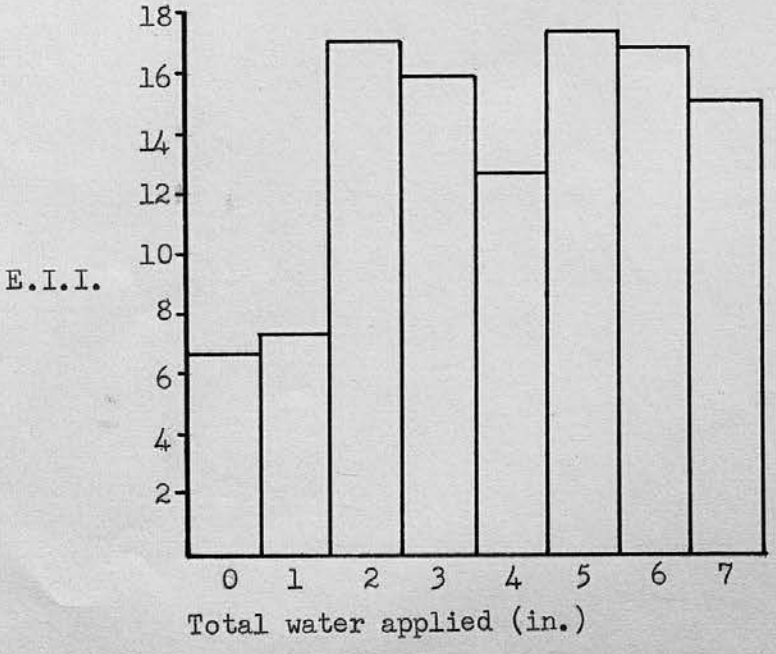
Fig. 12. Skin spot infection in relation to various watering treatments applied during 21 August to 2 October, 1970.



* No water applied during 21 August to 2 October.

Fig. 13. Mean skin spot surface and eye infection in relation to total water applied during 21 August to 2 October, 1970.





Boyd and Lennard (1962), that high levels of skin spot infection are associated with above average rainfall around the normal time of lifting. From the data, no conclusions could be drawn regarding the effect of timing of water application during this period. Surface infection became increasingly severe with increasing amount of water applied, up to the equivalent of 5 in. of rainfall. On the other hand, level of eye infection did not increase with increased amount of water applied above the equivalent of 2 in. of rainfall.

A_5 The effect of degree of skin spot infection of the seed stock and of planting distance upon emergence and yield of the subsequent crop.

This experiment was designed to investigate the effect of planting stocks of King Edward seed tubers showing different levels of skin spot infection, at different distances, upon rate of plant emergence and tuber yield of the subsequent crop.

Materials and Methods

King Edward seed tubers lifted by elevator digger on 24 October, 1968 and 22 October, 1969, at Highfield farm, East Lothian, were boxed and kept in an insulated store at approximately 4°C until April of the following year when assessments of skin spot infection were made. For the two years, prior to planting, separate stocks of tubers, showing different levels of skin spot infection were made up as follows:-

	Stock number	Percentage of tubers in different infection categories		
		"Slight" (All eyes infected)	"Slight" (Some eyes infected)	"Free/trace" (No eyes infected)
1969	1	-	-	100
	2	-	50	50
	3	-	100	-
	4	25	-	75
	5	50	-	50
	6	25	75	-
	7	50	50	-
	8	100	-	-

	Stock number	Percentage of tubers in different infection categories		
		"Slight" (All eyes infected)	"Slight" (Some eyes infected)	"Free/trace" (No eyes infected)
1970	1	-	-	100
	2	-	25	75
	3	-	50	50
	4	-	75	25
	5	-	100	-
	6	25	-	75
	7	50	-	50
	8	75	-	25
	9	25	75	-
	10	50	50	-
	11	75	25	-
	12	100	-	-

All stocks were planted out on 20 May, 1969 and 19 May, 1970, in plots of 32 tubers or 24 tubers, with planting distances of 11 in. and 16 in. respectively. In 1969, the plots were arranged in a randomised block layout with four replicates per seed stock and planting distance treatment but in 1970, they were arranged in a split-plot layout of three replicates per treatment, with the two planting distances forming sub-plots.

Emergence counts were taken throughout the growing season until constant and average rates of emergence and level of blanking calculated for all treatments.

The haulms of all plants were cut by hand on 29 September, 1969 and 17 September, 1970, and the crop lifted by elevator digger on 31 October and 30 September respectively. The produce

of each treatment was bagged and removed to an insulated store and kept at approximately 4°C until mid-December, 1969 and early October, 1970, when all treatments were dressed out into ware, seed and chat fractions.

Results

1. Plant emergence and percentage blanking. Average rates of plant emergence and percentage blanking in relation to skin spot infection of seed stock and planting distance in 1969 and 1970, are shown in Table 9.

   In 1969, plant emergence was generally delayed with increased level of skin spot infection of the seed stock, but this trend was less marked in 1970. The amount of blanking was generally small in both years but tended to increase with increasing stock infection, associated with at least some tubers with all eyes infected, in the main.

2. Tuber number and weight yield. Higher numbers of tubers per acre were produced in both years at the closer plant spacing from comparable stocks, while, at both spacings, tuber numbers tended to decline with increasing levels of skin spot infection of the seed stock (Table 10). Total weight yields were usually greater at the closer spacing, the increases relating mainly to higher seed yields. Increasing level of skin spot infection of the stock was associated with some reduction in total weight yield, more especially at the wider spacing: at the closer spacing, smaller seed crop yields from more severely affected stocks were to some extent off-set by higher ware yields. At the

wider spacing, ware yields were generally less affected by level of stock infection and seed yields, which again declined with increasing infection of the stocks, were more closely paralleled by total yields.

Table 9. Rate of plant emergence and % blanking in relation to level of skin spot infection of seed stock and plant spacing.

	Seed stock Skin spot infection			Average number of days to emergence		% Blanking	
	"Slight" (All eyes) %	"Slight" (Some eyes) %	"Free/trace" (No eyes) %	11 in. spacing	16 in. spacing	11 in. spacing	16 in. spacing
1969	-	-	100	34.5	35.0	0.0	0.0
	-	50	50	37.1	35.7	0.0	0.0
	-	100	-	39.6	38.2	0.0	0.0
	25	-	75	36.9	36.8	1.6	0.0
	50	-	50	39.8	39.6	8.6	5.2
	25	75	-	40.1	40.2	3.1	3.2
	50	50	-	41.9	42.5	5.5	1.1
	100	-	-	45.3	46.1	10.2	5.2
1970	-	-	100	31.7	33.0	0.0	0.0
	-	25	75	31.0	32.0	4.2	0.0
	-	50	50	31.3	32.3	0.0	2.8
	-	75	25	31.7	31.3	0.0	2.8
	-	100	-	31.0	31.3	0.0	0.0
	25	-	75	33.3	33.7	3.1	1.4
	50	-	50	33.3	34.7	1.0	1.4
	75	-	25	34.0	36.7	6.3	4.2
	25	75	-	30.0	32.0	0.0	0.0
	50	50	-	32.3	34.0	4.2	2.8
	75	25	-	36.0	35.3	1.0	5.6
	100	-	-	32.7	35.3	8.4	2.8

Table 10. Tuber number in relation to level of skin spot infection of seed stock and plant spacing (1000's/acre).

	Seed stock Skin spot infection			Plant spacing								
				11 in. spacing				16 in. spacing				
	"Slight" (All eyes) %	"Slight" (Some eyes) %	"Free/ trace" (No eyes) %	Ware >2¼ in.	Seed 1¼-2¼ in.	Chats <1¼ in.	Total	Ware >2¼ in.	Seed 1¼-2¼ in.	Chats <1¼ in.	Total
			SE ±	4.2	10.9	5.4	14.2	2.1	3.6	1.1	11.8
1969	-	-	100	21.8	190.6	44.1	256.4	34.4	152.5	27.4	214.3
	-	50	50	20.9	201.3	34.4	256.6	27.9	160.6	34.2	222.7
	-	100	-	24.7	157.4	23.7	205.9	34.2	152.2	26.0	212.4
	25	-	75	24.4	187.6	34.2	246.2	32.6	154.3	26.9	213.8
	50	-	50	25.8	179.4	27.6	232.7	34.0	126.4	19.7	180.1
	25	75	-	34.4	143.9	23.2	201.5	31.4	133.6	18.3	183.2
	50	50	-	32.8	134.8	18.4	186.0	35.8	131.1	21.1	188.0
	100	-	-	29.7	122.7	23.5	175.9	25.6	101.8	21.8	149.2
			SE ±	3.5	12.7	5.0	15.4	1.0	3.7	1.4	10.9
1970	-	-	100	15.6	196.9	47.3	259.9	21.5	167.1	30.4	240.4
	-	25	75	23.6	189.6	12.3	225.5	26.6	152.2	31.7	210.5
	-	50	50	18.8	208.7	41.9	269.4	28.2	142.5	22.1	192.8
	-	75	25	21.9	176.3	36.0	234.3	29.5	132.3	25.7	187.5
	-	100	-	29.9	157.7	42.8	230.4	34.0	100.0	20.4	154.3
	25	-	75	18.1	166.8	46.9	231.8	23.4	129.1	23.6	176.1
	50	-	50	22.6	179.9	35.1	237.7	24.7	139.1	26.6	190.3
	75	-	25	15.6	157.7	24.9	198.3	26.3	134.4	20.4	181.1
	25	75	-	23.1	183.3	36.9	243.3	29.1	141.9	30.1	201.1
	50	50	-	25.6	164.3	27.8	217.8	30.1	119.8	28.0	177.9
	75	25	-	31.9	150.7	34.0	216.6	25.7	106.4	20.8	152.9
	100	-	-	31.4	141.2	25.6	198.3	34.2	104.0	16.4	154.6

Table 11. Tuber weight in relation to level of skin spot infection of seed stock and plant spacing (tons/acre).

Seed stock Skin spot infection				Plant spacing								
				11 in. spacing				16 in. spacing				
	"Slight" (All eyes)	"Slight" (Some eyes)	"Free/trace" (No eyes)	Ware >2¼ in.	Seed 1¼-2¼ in.	Chats <1¼ in.	Total	Ware >2¼ in.	Seed 1¼-2¼ in.	Chats <1¼ in.	Total
	%	%	%								
			SE ±	0.6	0.7	0.1	0.8	0.4	0.3	0.1	0.5
1969	-	-	100	3.2	13.5	0.8	17.5	5.3	11.5	0.4	17.1
	-	50	50	3.2	13.7	0.7	17.6	4.1	9.8	0.6	14.6
	-	100	-	4.0	11.0	0.5	15.5	5.2	10.2	0.5	15.9
	25	-	75	3.8	12.9	0.6	17.2	4.9	9.7	0.5	15.1
	50	-	50	4.1	12.8	0.5	17.4	5.7	9.1	0.5	15.2
	25	75	-	5.8	10.5	0.5	16.8	5.2	9.4	0.4	15.0
	50	50	-	5.7	10.5	0.3	16.5	5.8	8.9	0.4	15.1
	100	-	-	5.3	9.4	0.4	15.1	5.0	7.3	0.4	12.7
			SE ±	0.7	0.8	0.1	1.1	0.2	0.2	0.1	0.3
1970	-	-	100	2.6	14.2	0.8	17.7	3.8	12.8	0.6	17.1
	-	25	75	4.3	13.8	0.7	18.8	4.7	11.3	0.6	16.6
	-	50	50	3.4	14.6	0.7	18.7	5.4	11.2	0.4	17.0
	-	75	25	4.0	12.2	0.7	16.8	5.8	10.8	0.5	17.0
	-	100	-	5.5	11.7	0.7	17.9	6.9	8.0	0.4	15.2
	25	-	75	3.3	12.0	0.8	16.1	4.4	10.5	0.4	15.3
	50	-	50	4.0	13.0	0.6	17.6	4.8	11.0	0.5	16.3
	75	-	25	2.8	12.1	0.5	15.4	4.9	9.0	0.4	14.3
	25	75	-	4.0	13.5	0.7	18.2	5.8	11.1	0.5	17.5
	50	50	-	5.1	12.2	0.5	17.8	6.0	9.5	0.5	16.0
	75	25	-	6.1	11.6	0.7	18.3	4.8	8.4	0.4	13.5
	100	-	-	5.9	10.8	0.5	17.2	6.5	8.5	0.3	15.3

Discussion

The adverse effects of skin spot infection of seed stocks upon subsequent plant emergence have already been described by previous workers (Boyd, 1957; Boyd and Lennard, 1961a; Hide, Hirst and Stedman, 1973). In this investigation, the delay in emergence and amount of blanking generally increased with an increase in the proportion of infected tubers, particularly tubers with all eyes infected, in the seed stock.

Associated with eye infection of the seed there was a reduction in numbers of tubers produced. This may be attributed in part to the reduction in plant population due to emergence failure and also to the reduction in main stem production from infected seed as shown in Experiment A_1. Reduced total weight yield was also obtained with increased level of seed infection, more especially where the wider spacing of 16 in. was used: the total yield reduction associated with more severe seed infection was greater in 1969 than in 1970, when total yields from the different seed stocks at the closer spacing of 11 in. showed no significant differences. Boyd and Lennard (1961a), indicated that the adverse effects of eye infection in causing delayed growth and blanking may not be sufficient to affect total yield due to the compensatory growth made by neighbouring plants, particularly where the stock is close planted: the present studies confirm that the extent of compensatory growth is less at 16 in. spacing, a normal ware spacing, than at 11 in. spacing, a normal seed spacing. From the results of artificial gapping experiments in a ware growing region, it is considered that field experiments will seldom distinguish significantly,

yield reductions due to blanking with fewer than 11 per cent gaps at emergence (Hirst, 1967; Hirst et al, 1971). In the present experiments, yield reductions were obtained with a much lower order of blanking. However, the previous workers, who used healthy plants, suggested that the debility of surviving plants in diseased crops would impair their ability to compensate and the effect of gaps might be more in diseased crops than with artificial gapping in healthy crops. The present results confirm that this is the case. With higher levels of infection in the stocks, seed yields were reduced at both spacings whereas ware yields were greater, except in one year, at the wider spacing.

DISCUSSION

The results indicate that soil-borne inoculum of O. pustulans, compared with seed inoculum, is relatively unimportant in the general level of transmission of the disease to progeny tubers. Infection of subsequent crops was found, at all times, to increase with increased level of seed infection. Assessment of underground stems and stolons showed that their colonisation by O. pustulans tended to be concentrated towards the seed tuber, i.e. colonisation was greater upon lower regions of the stems and upon the lower stolons. When soils were artificially inoculated with O. pustulans, the same pattern of colonisation was once again obtained. Thus, it would appear that infection is carried mainly from the seed tubers, via the growing stems and stolons, to the progeny tubers and that soil inoculum has little or no effect upon this pattern of transmission. Investigations into the over-wintering of O. pustulans in soil tend to support this, where it was found that, of the soils examined, the fungus could only persist to any extent, in sterilised soil. However, very low levels of inoculum persisting in field soils, would be of considerable significance as primary sources of contamination of seed stocks derived from stem cuttings and initially free from skin spot (Hirst et al, 1970).

Soil type was found to affect the level of skin spot infection of the subsequent crop. Of the soils examined, tuber infection was found to be least on light, sandy soils and greatest upon heavy, clay-loam soils. This may be associated with the water retention of these soils. High levels of skin spot infection are known to

occur with above average rainfall at normal times of lifting (Boyd and Lennard, 1962), and therefore tuber infection from clay-loam soils, which maintain relatively high soil moistures compared with lighter soils, will also be high. This effect of soil moisture upon subsequent skin spot infection was confirmed, when increased levels of tuber infection were obtained with increased total volume of water applied during August to October, after planting of seed tubers showing slight surface with some eye infection. The effect of soil type, however, may also be influenced by soil temperature. Boyd and Lennard (1962), found high levels of skin spot infection associated with below average temperatures at time of lifting and during early storage of the tubers. Lower temperatures tend to occur with heavy, wet soils and, therefore, skin spot infection in these soils will, again, be greater than that found in lighter, warmer soils.

The effects of level of seed infection upon plant emergence and crop yield were similar to those found by Boyd and Lennard (1961a) and Hirst, Hide and Stedman (1965, 1966, 1967 and 1973). Increase in level of seed infection was found, in general, to result in delayed plant emergence, increased blanking and associated reduction in main stem number. These, together, acted to shorten the effective growing season of the crops so that reduced total tuber numbers were also found to accompany increased level of seed infection. Reduction in tuber number may also have been the result of O. pustulans infection of stolons, causing reduced tuber initiation as suggested by Salt (1958). The effects of planting skin spot infected seed on total weight yield were more variable due to compensatory growth. Evidence

of this was provided in the increased ware tuber fractions found, at the expense of seed fractions, with higher levels of skin spot seed infection. Such effects of seed infection upon total tuber number and upon proportion of seed to ware tubers would, of course, be extremely important in the case of a crop being grown for seed purposes.

Rate of emergence and percentage blanking for all levels of seed infection were also affected by soil type. Emergence tended to be quicker and the incidence of blanking less, with light, sandy soils compared with heavier soils. This, once again, was probably the result of generally higher temperatures of light soils, enabling the sprouts, by more rapid extension, to overcome the growth inhibiting effects of eye infection. As a result of quicker emergence, the effective growing season was increased and higher tuber number and weight yields tended to be associated with the lighter soils.

Less compensatory growth occurred at wider plant spacing, i.e. at 16 in. compared with 11 in., and the ability to compensate is evidently less in diseased crops than in healthy crops. In such cases total yields are more likely to be affected by blanking or delayed emergence, as a result of skin spot infection of the seed tubers.

SECTION B Treatments for the control of skin spot in relation to subsequent field effects and skin spot development in the following crop.

The effects of various factors associated with the transmission and development of skin spot infection have been considered in Section A. The experimental work of this second section was concerned with the effects of various lifting, storage and chemical treatments of seed tubers upon the level of control of skin spot development and upon growth and yield of the subsequent crop. In previous investigations on the influence of time of haulm destruction and time of lifting, reduced levels of skin spot development have been reported with early haulm destruction or early lifting of crops, but the findings of different workers have been variable. In an attempt to clarify the position further, an experiment was carried out to investigate the effects of different times of haulm destruction and of lifting, upon skin spot development of tubers stored in various ways.

Storage conditions are known to influence the level of skin spot development, while effective control of the disease may be achieved by seed tuber disinfection with organo-mercury compounds at lifting, accompanied by subsequent box storage.

However, such disinfection is not always practicable to apply, on a commercial farm, at the optimum time desirable, i.e. at time of lifting. To investigate the effect of time of organo-mercury disinfection and of subsequent storage temperature upon skin spot development, an experiment was carried out where boxing and disinfection of seed tubers at lifting, was compared

with boxing and disinfection after various periods of clamp storage, the tubers then being stored at different temperatures. The effect of changing the storage temperature conditions of untreated and disinfected tubers upon skin spot development was also investigated.

Disinfection of tubers with organo-mercury solutions seldom eradicates completely the skin spot pathogen, and has been found to be ineffective against any surviving inoculum during crop growth. In addition, it creates a health hazard to the operators involved in its application. Therefore, studies were carried out on the use of a range of fungicides, to assess their effectiveness as alternatives to organo-mercury compounds.

The effects of seed tuber treatments upon yield and skin spot development of the subsequent crop, were also investigated.

The investigations are considered under the following headings:-

B_1 The effect of time of haulm destruction and time of lifting upon yield and skin spot development of the crop.

B_2 The effects of time of disinfection treatment and storage temperature upon skin spot development on seed tubers and upon emergence, yield and skin spot development of the subsequent crop.

B_3 The effect of varying temperature conditions during storage upon skin spot development of disinfected and untreated seed tubers and upon emergence, yield and skin spot development of the subsequent crop.

B_4 The effect of different fungicidal treatments of seed tubers at lifting upon level of skin spot infection after storage.

B_5 The effect of different fungicidal treatments of seed tubers at lifting or planting upon rate of emergence, yield and skin spot development of the subsequent crops.

B_1 The effect of time of haulm destruction and time of lifting upon yield and skin spot development of the crop.

This experiment was designed to investigate the effects of time of haulm destruction and time of lifting upon crop yield and level of skin spot infection of the crop after different storage treatments.

Materials and methods

A field scale trial was carried out in 1967, at Highfield farm, East Lothian, using a crop of King Edward, grown for seed purposes. The crop was planted in April with a commercial, FS certificate stock of seed tubers at a drill width of 28 in., and a seed spacing of 11 in., in a field which had not grown potatoes for six years. Within the crop, four adjacent plots, each consisting of 4, 400 yard (365 m.), drills, were allocated to three dates of haulm destruction by spraying with sulphuric acid:- (A) 23 August, (B) 6 September, (C) 20 September, 1967, while natural senescence of haulm was allowed to occur on plot (D), i.e. it was left unsprayed.

From plots (A), (B) and (C), tubers from short lengths distributed at random along the drills were lifted:- (1) On the date of haulm destruction, (2) 14 days later, (3) On 4 October, 1967. From plot (D), tubers were lifted on 4 and 17 October, 1967. Small samples of soil were also removed at random from within the plots, for estimation of soil moisture, on all dates of haulm destruction and on 4 and 17 October, (Table 12). At each date of lifting, samples of seed tubers were boxed, or boxed and disinfected as shown in Table 13.

Table 12. Percentage soil moisture at different times of lifting, 1967.

Date of lifting	% Soil moisture
23 August	13.7
6 September	18.1
20 September	11.4
4 October	21.5
17 October	22.6

Table 13. Storage treatments of tubers for different times of lifting and haulm destruction in 1967.

Date of haulm destruction	Date of lifting	Storage treatments
23 August	23 August	1. Boxed. 2. Boxed and disinfected.
	6 September	1. Clamped. 2. Boxed. 3. Boxed and disinfected
	4 October	1. Boxed.
6 September	6 September	1. Boxed. 2. Boxed and disinfected.
	20 September	1. Clamped. 2. Boxed. 3. Boxed and disinfected
	4 October	1. Boxed.
20 September	20 September	1. Boxed. 2. Boxed and disinfected.
	4 October	1. Clamped. 2. Boxed. 3. Boxed and disinfected
Natural senescence	4 October	1. Boxed. 2. Boxed and disinfected.
	17 October	1. Clamped. 2. Boxed. 3. Boxed and disinfected

Additional samples of tubers were lifted from each plot, 14 days after the respective date of haulm destruction or on 17 October, after natural senescence, and clamped. Tuber yield assessments were also made at these dates, by sampling 10, 5 yard (4.5 m.), strips of drill within the appropriate plot.

All clamps were covered with layers of baled straw and finally, soil and were of 10 cwt. capacity, with the exception of that made on October 4, which was of 30 cwt. capacity. Maximum and minimum temperatures for all clamps were recorded periodically throughout the storage period and are shown in Fig. 14.

Boxed tubers were placed in standard, wooden, chitting trays, using three trays per treatment, each holding approximately 35 lbs. tubers. Any obviously diseased or damaged tubers were avoided.

Disinfection of the tubers was carried out by dipping the boxes in a tank containing 15 gallons of organo-mercury solution, (methoxyethyl-mercuric-chloride, 1 lb. per 20 gallons water, equivalent to 150 ppm. mercury), for one minute then allowing them to drain. The tubers were not washed before dipping.

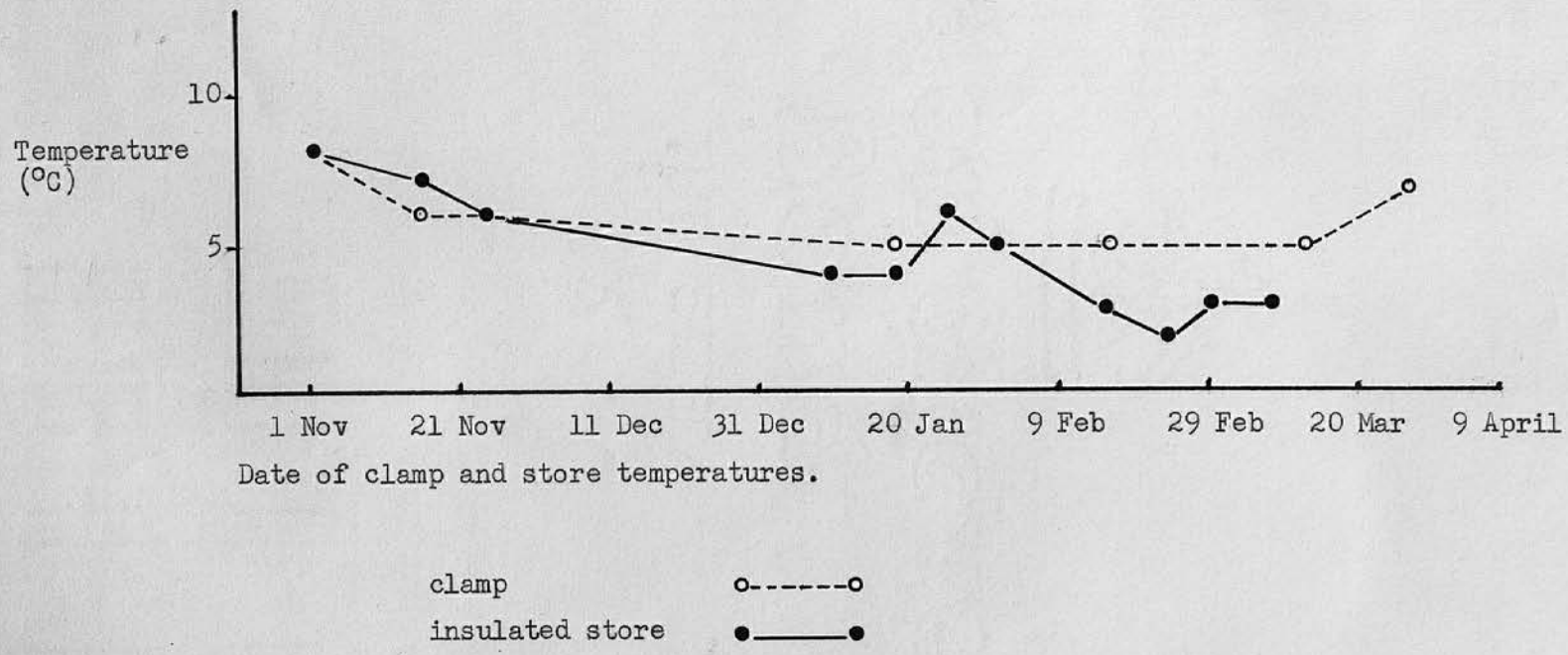
Tubers in all the boxed treatments were kept in an insulated store, (in which maximum and minimum temperatures were recorded, Fig. 14), at Fulford farm, Midlothian until April, 1968, when samples of 50 tubers were taken at random from each replicate of all treatments, washed and assessed for level of skin spot infection. Similar samples from the clamp treatments were also taken and assessed.

Results

1. The effects of time of haulm destruction upon tuber yield.

Increase in tuber yield, associated with an increase in ware yield, occurred with delay in haulm destruction until mid September (Table 14). The unexpectedly lower ware yield

Fig. 14. Mean median temperatures of clamps and insulated store, 1967-68.



obtained with natural senescence of the haulm, was probably the result of plot or sampling error.

Table 14. Tuber yield (tons/acre), in relation to times of haulm destruction in 1967.

Date of haulm destruction	Date of lifting	Yield (tons/acre) Ware	Seed	Total	Haulm decay (%)
23 August	6 September	8.2	10.1	18.8	0
6 September	20 September	9.6	10.3	20.5	5
20 September	4 October	10.7	10.4	21.8	25
Natural senescence	17 October	9.5	11.5	21.7	100

2. The effects of time of haulm destruction, time of lifting and of storage treatment upon skin spot development. Levels of skin spot development in relation to time of haulm destruction, time of lifting and storage treatment are shown in Table 15.

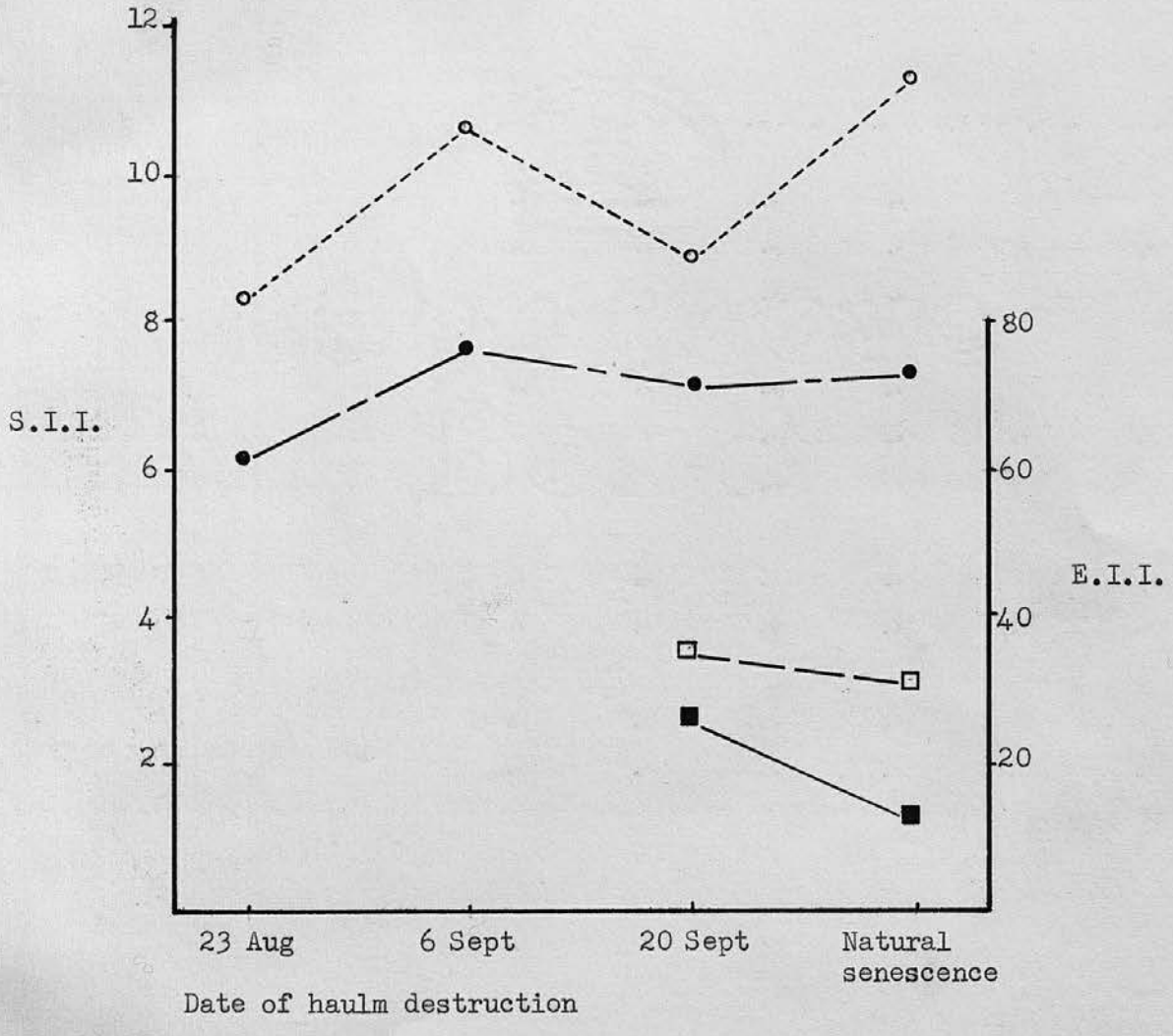
There was no obvious effect of time of haulm destruction upon subsequent skin spot development. For example, for tubers lifted 4 October and either boxed, or boxed and disinfected, the differences in levels of surface or eye skin spot development within each of the storage treatments, for different times of haulm destruction, were small and showed no consistent trend (Fig. 15).

Higher disease levels were generally recorded with later dates of lifting. This trend is illustrated in Fig. 16 with different storage treatments, the results for different times of haulm destruction having been averaged for each lifting date.

Table 15. Skin spot surface and eye infection indices in relation to time of haulm destruction, time of lifting and storage treatment, 1967.

Date of haulm destruction	Date of lifting	Storage treatment					
		Boxed and disinfected		Boxed alone		Clamped alone	
		S.I.I.	E.I.I.	S.I.I.	E.I.I.	S.I.I.	E.I.I.
23 August	23 August	1.1	16.0	5.6	61.0	-	-
	6 September	1.9	40.0	6.5	50.0	18.3	64.0
	4 October	-	-	8.4	62.0	-	-
6 September	6 September	1.5	33.0	6.4	65.0	-	-
	20 September	1.3	28.0	10.4	65.0	26.8	89.0
	4 October	-	-	10.7	77.0	-	-
20 September	20 September	1.1	20.0	13.3	76.0	-	-
	4 October	2.7	36.0	8.9	73.0	21.3	72.0
Natural senescence	4 October	1.3	31.0	11.3	73.0	-	-
	17 October	5.1	47.0	17.4	75.0	46.7	81.0

Fig. 15. Skin spot surface and eye infection indices, in relation to time of haulm destruction and storage treatment of tubers lifted 4 October, 1967.



S.I.I.

Boxed only

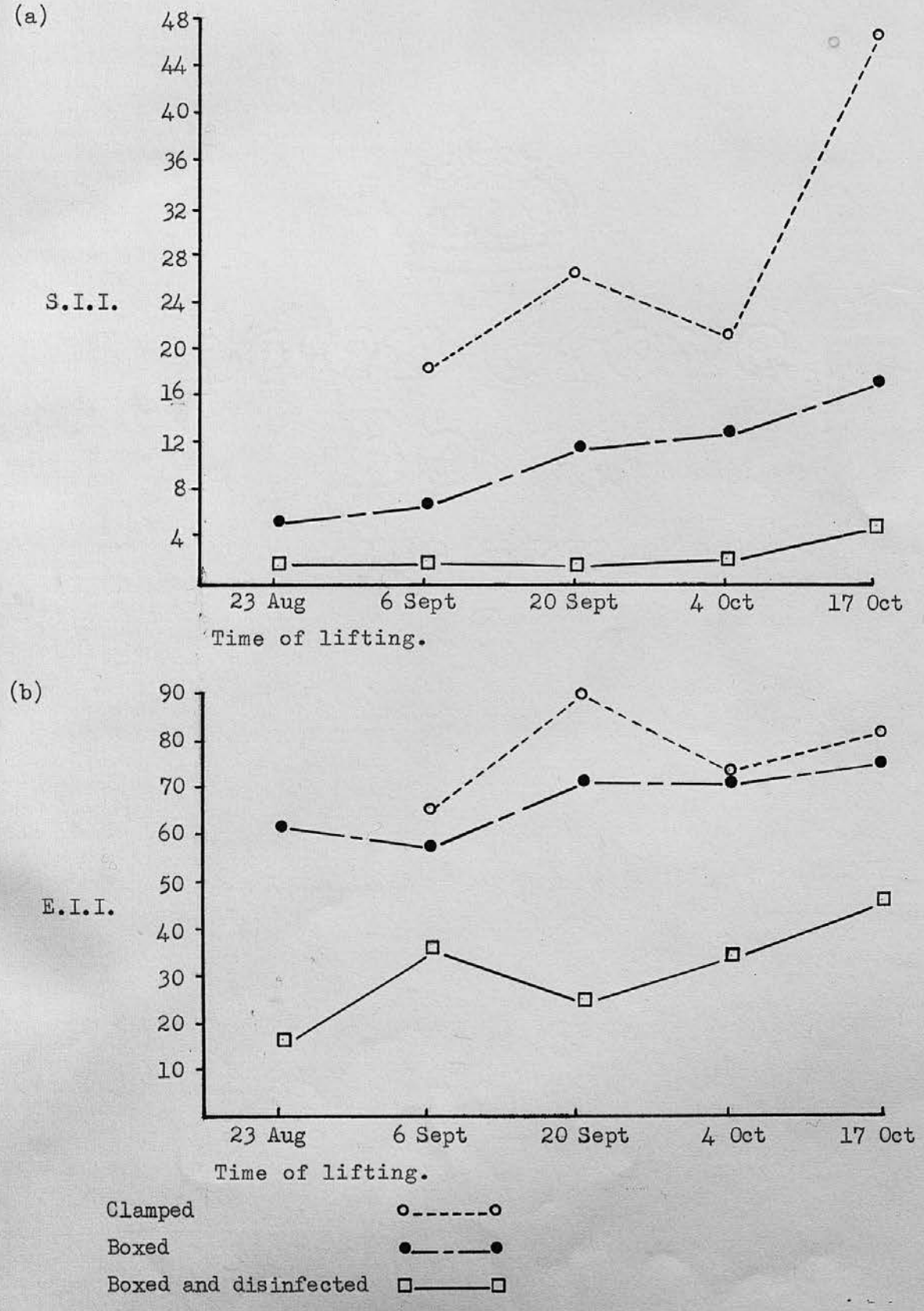
Boxed and disinfected

E.I.I.

Boxed only

Boxed and disinfected

Fig. 16. Skin spot surface and eye infection indices averaged for different times of haulm destruction, in relation to time of lifting and storage treatment of tubers.



In the case of clamp storage, levels of skin spot were generally high. Time of lifting had little effect upon subsequent skin spot development except with tubers lifted 17 October, which showed exceptionally high levels of surface infection.

With boxed tubers, reduced surface infection was obtained at all times of lifting, compared with clamped tubers. With delay in lifting, the level of skin spot of boxed tubers increased, this relationship being more marked with surface infection than with eye infection, which was only slightly less than that of clamped tubers.

At all lifts, boxing and disinfection of tubers afforded the most effective and consistent measure of control, with a tendency towards better results from earlier lifting, particularly in the case of eye infection.

Discussion

Although Boyd (1957), reported reduced levels of skin spot development with early haulm destruction, Lennard (1967) and McGee (1967), found no marked differences in disease levels related to different dates of haulm destruction. The results of the present work are in keeping with the findings of the later workers. In a season when haulm growth persisted into late September, earlier haulm destruction gave lower yields, mainly associated with lower ware yield.

Disease development was affected by time of lifting, higher levels being recorded with later dates of lifting. This may be attributed in part, to the exposure of tubers to conditions of increasing soil moisture (Table 12), and possibly decreasing temperatures, with delay in lifting.

The generally high levels of skin spot associated with clamp storage may be related to the exposure of tubers to conditions of high humidity and low temperature (Fig. 14), such conditions being recognized to favour skin spot development (Boyd and Lennard, 1962). Thus, irrespective of the time of lifting, subsequent clamping of tubers will tend to encourage high levels of skin spot development. The marked increase in surface infection with late lifting in mid-October, followed by clamping, may possibly have been the result of increased humidity within that particular clamp, due to higher soil moisture levels at lifting of the tubers and to less drying out of the clamp, prior to applying a soil cover, as a result of damper atmospheric conditions later in the season. Since eye skin spot infection did not show a corresponding increase, it had presumably already reached a maximum in the soil, before mid-October.

The reduction in surface skin spot infection obtained with boxing of tubers after lifting, compared with clamping, may be attributed to the exposure of the tubers to dry conditions, which would check fungal activity at their surface. However, the reduction in infection level was most marked for earlier times of lifting only, and, with delay in time of lifting, there was a significant increase in subsequent skin spot development of boxed tubers. This increase in infection may have been due to decreasing ambient storage temperatures, encouraging skin spot development, or to the disease establishment in the field having reached a stage where it was no longer checked by dry conditions. The less effective control of eye infection, compared with that of surface infection, with early lifting and boxing, may be

attributed to the eye infection being established earlier in the season than surface infection, because of the delicate nature of the eye tissues and the absence of a cork periderm around the eyes.

The most consistent and effective control of skin spot was obtained by disinfection in an organo-mercury solution of boxed tubers at lifting. Maximum control tended to occur with early lifting, particularly of eye infection, although the level of control achieved with boxing and disinfection carried out on 17 October still compared favourably with that obtained with boxing in late August.

B_2 The effect of time of disinfection treatment and storage temperature upon skin spot development on seed tubers and upon emergence, yield and skin spot development of the subsequent crop.

This experiment was designed to investigate the effect of delaying the time of disinfection of seed tubers, stored in clamps from lifting, and of the temperature of storage in boxes upon skin spot development and upon rate of emergence, yield and skin spot development of the subsequent crop.

Materials and Methods

King Edward seed tubers lifted by hand on 4 October, 1967 and by elevator digger on 24 October, 1968 and 22 October, 1969, were placed in clamps of 30 cwt. capacity on Highfield farm, East Lothian. The tubers were covered initially with baled straw and finally with 4 in. of soil. On the date of clamping and at subsequent intervals throughout the storage period, random samples of tubers were removed from the clamps, placed in standard, wooden, chitting trays, at the rate of approximately 35 lb. tubers per tray, and either disinfected or left untreated. There were two boxes per treatment. The disinfection treatment involved dipping the boxes for one minute in a tank containing 15 gallons organo-mercury solution (methoxyethyl-mercuric-chloride, 150 ppm. Hg.), allowing them to drain and stacking them alongside the boxed, untreated tubers. All treatments were removed to insulated stores and kept at approximately $4^{\circ}C$ in 1967 and either $4^{\circ}C$ or $10^{\circ}C$ in 1968 and 1969. In March of the

following year, random, 50-tuber samples were removed from each replicate, washed and assessed for skin spot development.

In 1969 and 1970, random samples of tubers from the various treatments stored at 4°C were planted out at a spacing of 11 in. with 21 tubers per plot, in a randomised block layout of four replicates per treatment. In addition, samples of tubers lifted on 9 and 26 September in 1968 and 1969 respectively and either boxed or boxed and disinfected at lifting, were also planted out. Dates of lifting and of removal of seed tubers from clamp storage for subsequent planting out, were as follows:-

	1969	1970
lifted	9 September, 1968	26 September, 1969
lifted	24 October, 1968	22 October, 1969
from clamp	5 December, 1968	5 December, 1969
from clamp	6 February, 1969	6 February, 1970
from clamp	10 April, 1969	14 April, 1970

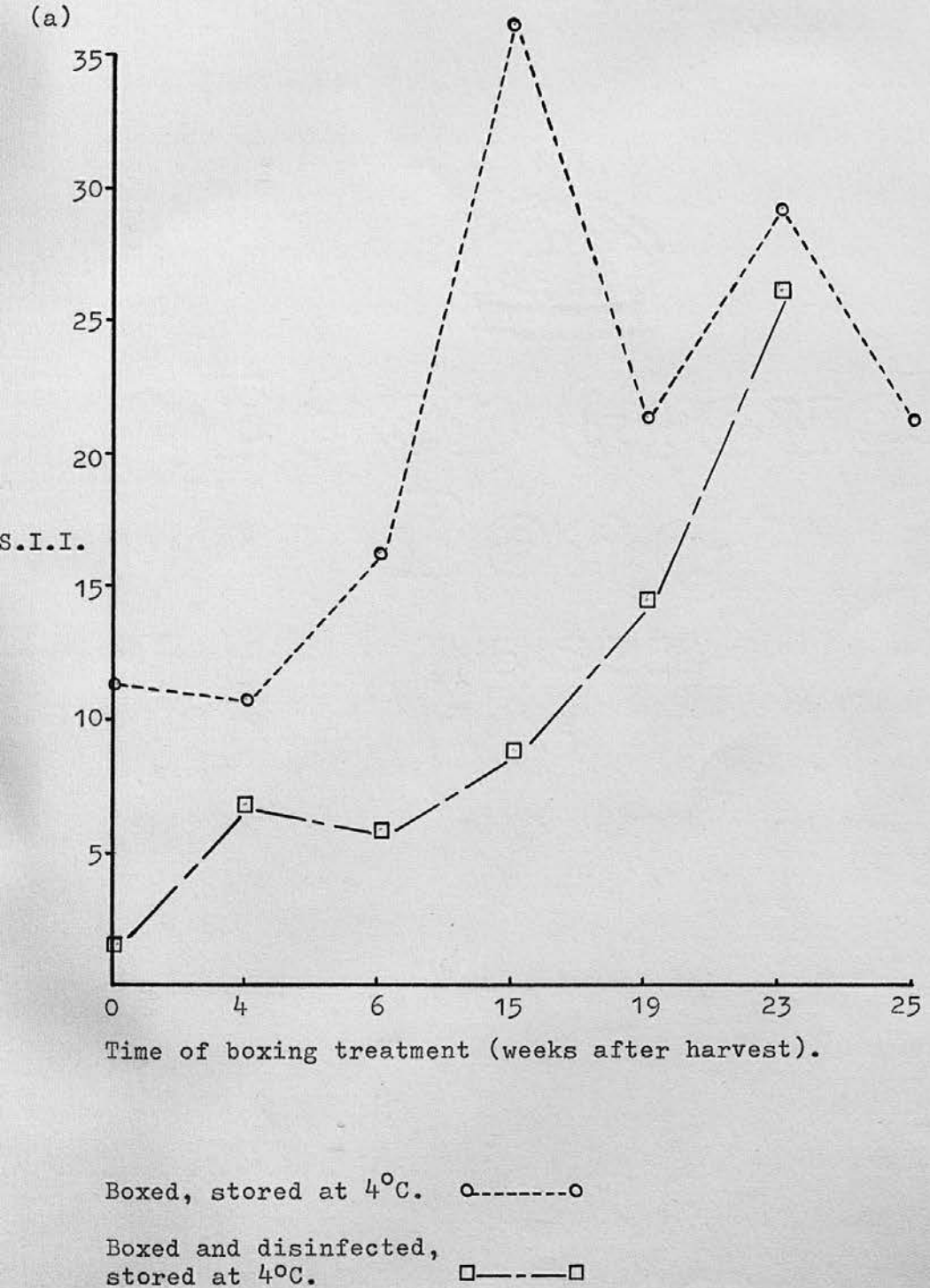
Prior to planting in 1969, three 20-tuber samples were taken from each treatment and the maximum sprout length and number of sprouts of 2 mm. or above, recorded for each tuber. Emergence counts were taken for all plots, throughout the growing season, until constant, and average rates of emergence calculated for all treatments. The haulms of all plants were cut by hand on 1 October, 1969 and 15 September, 1970 and the crop lifted by elevator digger on 30 October and 30 September respectively. The produce of each treatment was bagged and subsequently dressed out into ware, seed and chat fractions. From the 1969 planting, samples of seed tubers from all treatments were kept at 4°C until mid-July, 1970, when assessments of skin spot development were made.

Results

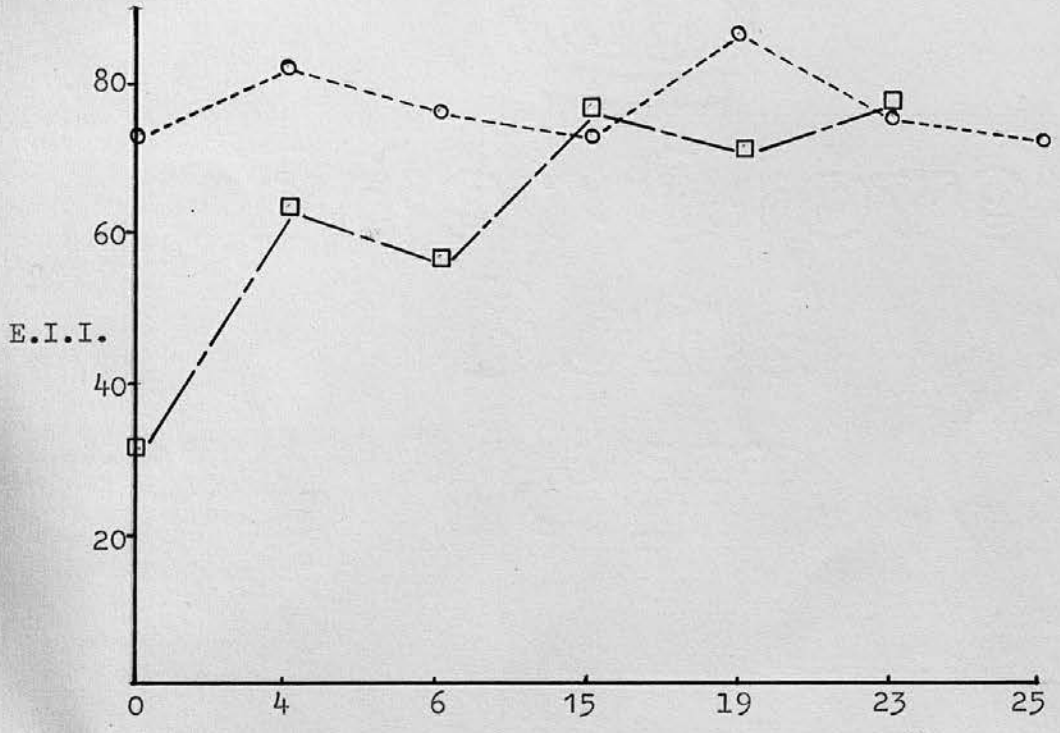
1. Skin spot development. The results of assessments of skin spot in relation to different boxing treatments following clamp storage from lifting in 1967, 1968 and 1969, are shown in Fig. 17-19 (Appendix XIII). In general, levels of skin spot infection were similar in each year although, higher surface infection tended to occur in 1967 than in 1968 or 1969. In each year, lower levels of infection were obtained from the earlier boxed and disinfected treatments, compared with boxed only treatments, carried out at the same time. Although the effectiveness of disinfection treatment decreased with delay in removal of the tubers from clamp storage, a reasonable level of control was achieved, in each year, up until six weeks after lifting. Compared with continuous clamp storage, boxing at lifting gave some slight control of surface infection, when carried out up until six weeks after lifting. No reduction, however, in eye infection was achieved at any time with boxing, compared with clamp storage. In 1968 and 1969, the temperature of box storage was found to have no marked effect upon skin spot development of either disinfected or untreated tubers although, in 1968, slightly lower surface and eye infection indices tended to be associated with the higher temperature of storage.

2. Tuber sprout length. From the results of sprout counts, on tubers stored at $4^{\circ}C$ in 1969 (Table 16), boxing and disinfection of tubers at lifting and after various periods of clamp storage, up until 6 February, 1969, resulted in a

Fig. 17. Skin spot surface and eye infection indices in relation to different box storage treatments, following clamp storage from lifting on 4 October, 1967.



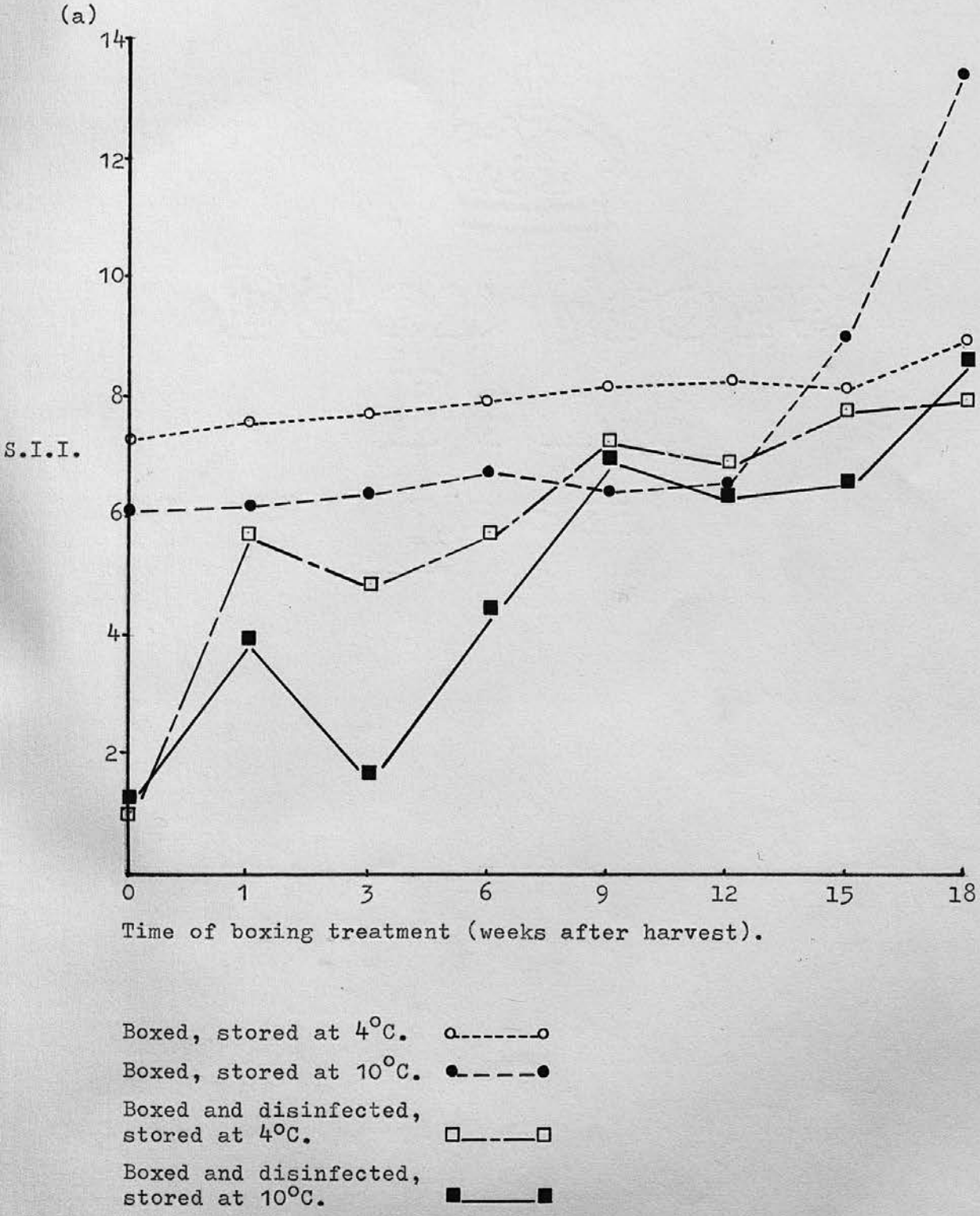
(b)

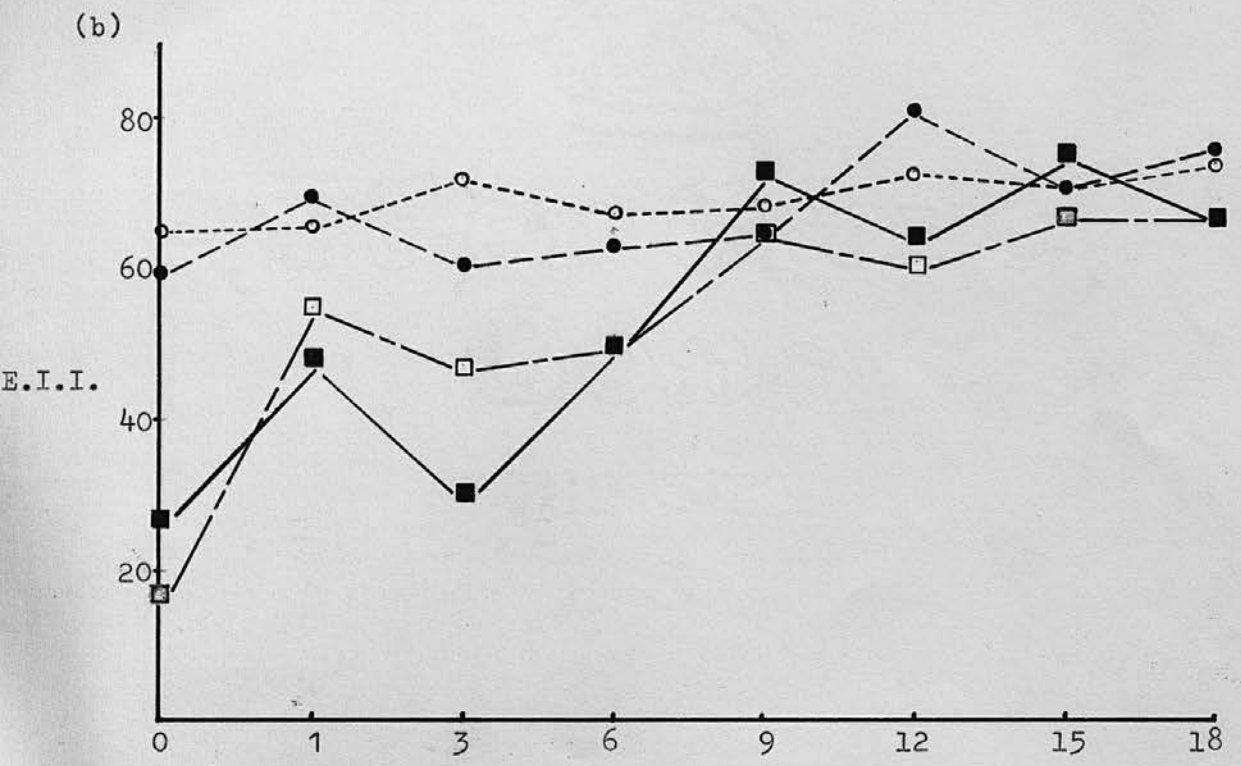


Boxed, stored at 4°C. o------o

Boxed and disinfected, stored at 4°C. □—-—□

Fig. 18. Skin spot surface and eye infection indices in relation to different box storage treatments, following clamp storage from lifting on 24 October, 1968.





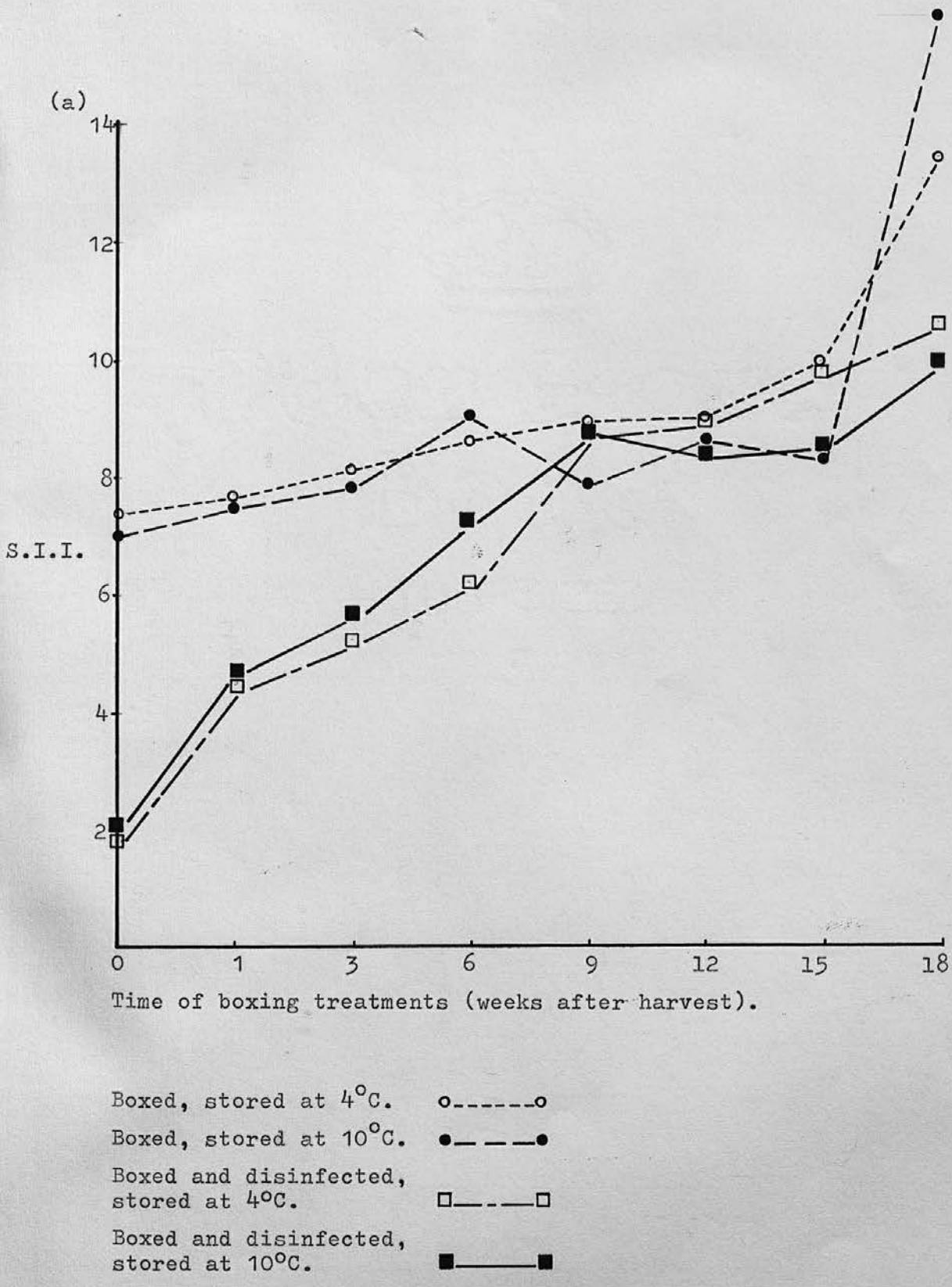
Boxed, stored at 4°C. o------o

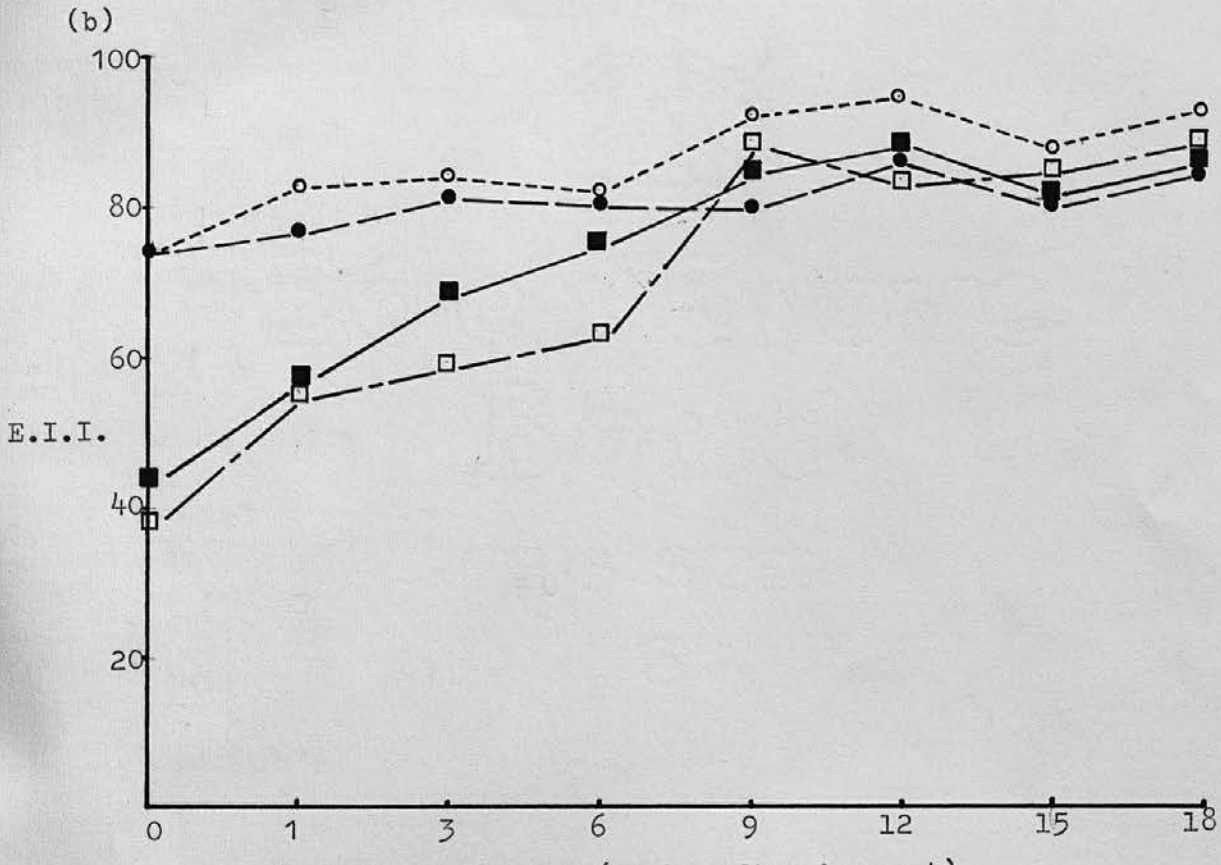
Boxed, stored at 10°C. ●— — —●

Boxed and disinfected, stored at 4°C. □— — —□

Boxed and disinfected, stored at 10°C. ■———■

Fig. 19. Skin spot surface and eye infection indices in relation to different box storage treatments, following clamp storage from lifting on 22 October, 1969.




(b)
100
80
60
E.I.I.
40
20
0
1
3
6
9
12
15
18
Time of boxing treatments (weeks after harvest).
Boxed, stored at 4°C.
Boxed, stored at 10°C.
Boxed and disinfected, stored at 4°C.
Boxed and disinfected, stored at 10°C.

stimulation of sprout growth, compared with boxing only. Maximum stimulation occurred with early lifted tubers and became less as boxing, or boxing and disinfection, was delayed. There was no effect of seed tuber treatment upon the mean length of the longest sprout, apart from the slightly longer sprouts produced by early lifted tubers.

Table 16. Sprout length of King Edward seed tubers prior to planting in 1969, in relation to time of boxing and disinfection.

Time of seed tuber treatment	Boxed and disinfected		Boxed only	
	Mean length of longest sprout (mm.)	Number of sprouts >2 mm.	Mean length of longest sprout (mm.)	Number sprouts >2 mm.
At lifting, 9 September, 1968	3.3	5.8	3.2	2.4
At lifting, 24 October, 1968	3.5	3.1	3.0	1.8
From clamp, 5 December, 1968	3.6	3.0	2.8	1.0
From clamp, 6 February, 1969	3.2	2.3	3.0	1.3
From clamp, 10 April, 1969	2.4	1.5	2.8	1.4

3. Rate of emergence. From the rate of plant emergence and associated blanking data, shown in Table 17, delayed boxing, and boxing and disinfection treatment of seed tubers was found, in 1969 and 1970, to result in delayed emergence and increased blanking of the subsequent crop. In general, plant emergence was slower and percentage blanking was usually greater with boxed, untreated tubers compared with boxed and

disinfected tubers. It is not known, however, why emergence should be relatively slow and blanking unexpectedly high, for seed tubers lifted early in 1969.

Table 17. Rate of emergence and degree of blanking of King Edward seed tubers in relation to time of boxing and disinfection.

Time of seed tuber treatment	Average number of days to emergence		% Blanking	
	Boxed and disinfected	Boxed only	Boxed and disinfected	Boxed only
1969				
At lifting, 9 September, 1968	33.6	33.8	0.0	0.0
At lifting, 24 October, 1968	33.1	31.8	0.0	0.0
From clamp, 5 December, 1968	34.5	36.7	0.0	1.3
From clamp, 6 February, 1969	35.0	37.3	0.0	1.3
From clamp, 10 April, 1969	36.9	37.1	5.0	1.3
1970				
At lifting, 26 September, 1969	40.2	42.8	9.5	6.0
At lifting, 22 October, 1969	38.5	39.2	0.0	2.4
From clamp, 5 December, 1969	39.5	43.2	0.0	13.1
From clamp, 6 February, 1970	40.0	50.0	3.6	11.9
From clamp, 14 April, 1970	43.8	41.5	10.9	11.9

4. Tuber yield. Tuber yield assessments in relation to time of boxing and disinfection of seed tubers are shown in Tables 18 and 19. Boxing and disinfection was found, at all times of treatment, to give increased total tuber number in the subsequent crop, associated with higher seed weight yields, compared with boxed, untreated tubers. However, greater ware yields were found to occur with untreated tubers, resulting in only a slight, but fairly consistent, total weight yield advantage being associated with boxed and disinfected seed tubers. Increasing delay in time of boxing tubers after lifting in October, generally resulted in decreased total tuber number and some decline in weight yield with both untreated and disinfected tubers. Seed tubers lifted in September, 1968 and 1969, gave lower tuber numbers but usually similar weight yields, compared with those lifted in October.

5. Subsequent skin spot development. Assessments of skin spot infection in relation to time of boxing and disinfection of seed tubers in 1968 and 1969, are shown in Table 20. Moderate levels of infection were found from most treatments but there were no marked differences associated with time of boxing and disinfection of seed tubers. Boxed and disinfected tubers, however, tended to give slightly less skin spot development, compared with boxed only tubers and highest subsequent infection was found with late boxed and untreated tubers.

Table 18. Tuber yield in relation to time of boxing and disinfection of King Edward seed tubers - 1000s/acre.

Time of seed tuber treatment	Boxed and disinfected				Boxed only			
	Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
1969 SE ±	3.2	9.4	4.2	14.7	2.7	5.1	1.2	7.4
At lifting, 9 September, 1968	13.5	222.7	26.7	262.9	20.9	161.8	21.7	204.3
At lifting, 24 October, 1968	7.6	231.6	35.9	275.1	19.6	176.0	26.7	222.4
From clamp, 5 December, 1968	9.2	220.6	45.9	275.6	24.2	154.4	19.1	197.7
From clamp, 6 February, 1969	15.3	203.5	26.0	244.8	18.1	168.4	24.2	210.7
From clamp, 10 April, 1969	12.7	185.7	27.5	226.0	23.7	144.2	17.1	184.9
1970 SE ±	4.8	10.2	3.9	13.7	2.1	4.6	1.7	6.1
At lifting, 26 September, 1969	39.2	125.3	28.5	193.1	42.6	117.2	18.5	178.3
At lifting, 22 October, 1969	40.6	154.9	31.4	226.8	37.5	126.9	26.3	190.7
From clamp, 5 December, 1969	39.2	129.4	21.9	190.6	41.0	112.3	27.5	180.8
From clamp, 6 February, 1970	38.2	150.0	26.5	214.7	34.1	93.5	27.7	155.4
From clamp, 14 April, 1970	40.6	109.0	21.6	171.2	34.1	92.9	19.9	146.9

Table 19. Tuber yield in relation to time of boxing and disinfection of King Edward seed tubers - tons/acre.

Time of seed tuber treatment	Boxed and disinfected				Boxed only			
	Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
1969 SE ±	0.8	1.0	0.1	1.1	0.5	0.4	0.1	0.6
At lifting, 9 September, 1968	2.0	15.8	0.5	18.4	3.8	12.6	0.5	16.9
At lifting, 24 October, 1968	1.2	16.0	0.6	17.8	3.3	13.4	0.5	17.1
From clamp, 5 December, 1968	1.5	15.0	0.8	17.3	4.1	12.2	0.4	16.7
From clamp, 6 February, 1969	2.3	14.8	0.5	17.7	3.2	12.6	0.6	16.4
From clamp, 10 April, 1969	2.2	12.6	0.7	15.5	4.2	11.7	0.3	16.1
1970 SE ±	0.9	0.7	0.1	0.9	0.4	0.3	0.1	0.4
At lifting, 26 September, 1969	6.3	8.8	0.4	15.6	7.2	8.3	0.2	15.7
At lifting, 22 October, 1969	6.2	10.3	0.4	17.0	6.6	8.9	0.3	15.8
From clamp, 5 December, 1969	6.7	8.9	0.3	15.9	7.2	8.0	0.4	15.6
From clamp, 6 February, 1970	6.2	9.9	0.4	16.6	6.2	6.6	0.5	13.3
From clamp, 14 April, 1970	7.0	7.5	0.4	15.0	6.3	6.8	0.3	13.3

Table 20. Skin spot infection of the subsequent crop in relation to time of boxing and disinfection of King Edward seed tubers.

Time of seed tuber treatment	Boxed and disinfected		Boxed only	
	S.I.I.	E.I.I.	S.I.I.	E.I.I.
At lifting, 9 September, 1968	7.2	49.3	8.2	52.5
At lifting, 24 October, 1968	7.3	40.7	8.6	62.9
From clamp, 5 December, 1968	9.4	53.5	9.0	52.5
From clamp, 6 February, 1969	7.9	60.3	8.6	60.8
From clamp, 10 April, 1969	7.5	42.5	13.3	75.4

Discussion

The decreased effectiveness of organo-mercury disinfection of tubers, in the control of skin spot, found with delay in application, may be attributed to the failure of the organo-mercury solution to penetrate to the depth of tuber tissue at which the fungus had become established. During clamp storage, tubers are exposed to conditions of high humidity and low temperature, which favour growth of the fungus (Boyd and Lennard, 1962). Therefore, with extended clamp storage, deeper infection of tuber tissues will occur and if organo-mercury is to control such infection, it must also penetrate to such depths. Hamilton and Ruthven (1967), however, found reduced penetration of tuber tissues by organo-mercury, with delay in disinfection treatment after lifting.

With both boxing treatments there was a tendency for a slight improvement in the level of control achieved by storing tubers at 10°C rather than 4°C.

The reduction in surface infection obtained with boxing of tubers, up until six weeks after lifting, compared with continuous clamp storage, may be attributed to the exposure of the tubers to dry conditions, which would check fungal growth at the tuber surface. With delay in boxing, until six weeks after lifting, presumably infection had become too well established, as a result of exposure to favourable conditions during clamp storage,to be much affected by decreased storage humidity.

The stimulative effect of boxing and disinfection of seed tubers upon sprout growth, compared with untreated tubers, was reflected in more rapid rates of plant emergence and increased tuber yields, obtained from boxed and disinfected tubers. Reduced total tuber number and, to a lesser extent, total tuber weight found with delayed seed tuber treatment, was associated with reduced sprout growth and slower subsequent emergence.

Comparison of skin spot development of the subsequent crops, with that of the corresponding seed tubers, in relation to their time of boxing and disinfection, showed that reduced levels of infection obtained with early seed tuber treatment, was not carried over into the subsequent crop. Reduced seed tuber infection, however, resulting from boxing and disinfection, was found to produce a slight reduction in infection of the subsequent crop, compared with boxing only.

B_3 The effect of varying temperature conditions during storage upon skin spot development of disinfected and untreated seed tubers and upon emergence, yield and skin spot development of the subsequent crop.

This experiment was designed to investigate the effects of different storage temperature treatments of disinfected or untreated seed tubers upon skin spot development and upon rate of plant emergence, yield and skin spot development of the subsequent crop.

Materials and methods

In 1967, at Highfield farm, Midlothian, seed size King Edward tubers which had been lifted and clamped on 4 October, following haulm destruction with sulphuric acid on 20 September, were removed from the clamp on 1 November and placed in standard, wooden, chitting trays at the rate of approximately 35 lb. of tubers per tray. The trays were then transferred to insulated stores and kept at either 4°C or 10°C until 12 January, 2 February or 23 February, 1968. On each of these dates, two boxes per treatment were transferred to the alternative temperature. In addition, boxes were kept constantly at each temperature until April, 1968, when two random, 50-tuber samples were removed from all treatments, washed and assessed for skin spot infection.

In seasons 1968-69 and 1969-70, seed size King Edward tubers were lifted by elevator digger at Highfield farm, on 24 October, 1968 and 20 October, 1969, two weeks after haulm destruction. The tubers were placed in trays and either disinfected for one minute in an organo-mercury solution

(150 ppm. Hg.), or left untreated. All boxes were then removed to insulated stores and kept at either 1-7°C (4°C) or 5-13°C (9°C) in 1968-69 and either 3-7°C (5°C) or 4-10°C (7°C) in 1969-70. On each of the dates shown in Table 21, two boxes per treatment were transferred from one storage temperature to the alternative temperature.

Table 21. Date of seed tuber transfer to alternative storage temperature, 1968-69 and 1969-70.

1968-69	1969-70
6 December, 1968	26 November, 1969
17 January, 1969	24 December, 1969
28 February, 1969	21 January, 1970
-	18 February, 1970

A further two boxes were retained at each of the initial temperatures until May, 1969 and April, 1970, when three random 40-tuber samples were removed from all treatments, washed and assessed for skin spot development.

On 21 May, 1969 and 12 May, 1970, tuber samples from all treatments were planted out in field plots in a randomised block layout replicated three times, with two plots of 16 tubers, at a spacing of 11 in., per treatment in each block. Prior to planting in 1969, three 20-tuber samples were taken from each treatment and assessed for maximum sprout length and numbers of sprouts exceeding 2.0 mm. in length. Emergence counts were taken for all plots throughout the growing season until found constant

and average rates of emergence calculated for all treatments. The haulms of all plants were cut on 29 September, 1969 and 16 September, 1970 and the crops lifted by elevator digger on 30 October and 30 September, respectively. The produce of each treatment was dressed out and yields of ware, seed and chats assessed. In 1969, seed tuber samples of all treatments were kept at 4°C until April, 1970, when assessments of skin spot infection were made.

Results

1. Skin spot development. In 1967-68 (Table 22), storage at 10°C induced strong sprout growth which interfered with the eye infection assessments made in April. This is particularly evident in the low figure of 4.0 for continuous storage at this temperature. The eye infection indices may thus be all too low, while the surface infection indices give a more reliable assessment. The results show that the longer the tubers were kept at 10°C, before transferring to 4°C, the less the skin spot development. Conversely, the longer the tubers were kept at 4°C, before transferring to 10°C, the greater the skin spot development. The lowest infection level was with continuous storage at 10°C, and the highest with continuous storage at 4°C: the influence of the higher temperature was slightly greater when imposed during the first period of storage rather than in the latter part, towards planting time.

In both 1968-69 and 1969-70 (Tables 23 and 24), boxing and disinfection gave an appreciable reduction in level of both surface and eye skin spot infection, compared with boxed tubers only. There was no evidence, however, that the subsequent storage temperature conditions had any marked effect upon the levels of surface or eye infection found with either treatment.

Table 22. Skin spot infection of boxed tubers subjected to varying storage temperatures, 1967-68.

Storage temperature treatment	Date of transfer	Boxed only	
		S.I.I.	E.I.I.
From 10°C to 4°C	12 January, 1968	5.7	47.0
From 10°C to 4°C	2 February, 1968	4.9	41.0
From 10°C to 4°C	23 February, 1968	3.7	48.0
Continuous 10°C	-	2.0	4.0
From 4°C to 10°C	12 January, 1968	6.4	33.0
From 4°C to 10°C	2 February, 1968	6.4	42.0
From 4°C to 10°C	23 February, 1968	8.9	54.0
Continuous 4°C	-	10.7	82.0
Clamped	-	21.3	72.0

2. Sprout growth. From assessments of average length of the longest sprout per tuber, in relation to different boxing treatments, in 1968-69 (Table 25), longer periods of storage at 4°C, before transfer to 9°C, were associated with reduced sprout length. Conversely, longer periods of storage at 9°C, before transfer to 4°C, gave increased sprout length.

Table 23. Skin spot infection of disinfected and untreated tubers subjected to varying storage temperatures, 1968-69.

Storage temperature treatment	Date of transfer	Boxed and disinfected		Boxed only	
		S.I.I.	E.I.I.	S.I.I.	E.I.I.
From 9°C to 4°C	6 December, 1968	0.8	15.9	*	*
From 9°C to 4°C	17 January, 1969	0.9	13.1	*	*
From 9°C to 4°C	28 February, 1969	0.6	10.4	*	*
Continuous 9°C	-	1.3	26.9	6.1	59.8
From 4°C to 9°C	6 December, 1968	0.8	18.2	7.5	74.0
From 4°C to 9°C	17 January, 1969	0.5	8.0	7.5	80.0
From 4°C to 9°C	28 February, 1969	0.8	14.3	8.0	76.2
Continuous 4°C	-	1.0	16.4	7.4	65.3

* Not recorded.

Table 24. Skin spot infection of disinfected and untreated tubers subjected to varying storage temperatures, 1969-70.

Storage temperature treatment	Date of transfer	Boxed and disinfected		Boxed only	
		S.I.I.	E.I.I.	S.I.I.	E.I.I.
From 7°C to 5°C	26 November, 1969	1.9	40.2	7.3	73.9
From 7°C to 5°C	24 December, 1969	1.6	38.3	7.1	72.8
From 7°C to 5°C	21 January, 1970	1.5	37.9	7.0	73.1
From 7°C to 5°C	18 February, 1970	1.5	35.3	7.2	78.2
Continuous 7°C	-	1.9	43.5	7.0	73.1
From 5°C to 7°C	26 November, 1969	1.6	40.4	7.2	68.9
From 5°C to 7°C	24 December, 1969	1.7	43.2	7.5	72.7
From 5°C to 7°C	21 January, 1970	1.6	38.1	7.2	71.6
From 5°C to 7°C	18 February, 1970	1.5	36.1	7.8	78.4
Continuous 5°C	-	1.6	38.1	7.9	73.2

Continuous storage at 4°C or storage at 4°C during the later period of storage, gave shorter sprout growth, for both untreated and disinfected tubers, compared with continuous storage at 9°C or storage at 9°C during the later period of storage. In the case of boxed, untreated tubers, later storage at the lower temperature, however, gave increased numbers of sprouts per tuber, over 2 mm. Longer sprouts tended to occur with boxed, untreated tubers than with disinfected tubers, which, however, gave increased numbers of sprouts per tuber over 2 mm. in length.

Table 25. Sprout growth of disinfected and untreated seed tubers subjected to varying storage temperatures, 1968-69.

Storage temperature treatment	Date of transfer	Boxed and disinfected		Boxed only	
		Mean length of longest sprout (cm.)	Number of sprouts > 2 mm.	Mean length of longest sprout (cm.)	Number of sprouts > 2 mm.
From 9°C to 4°C	6 Dec, 1968	0.4	3.1	0.3	2.5
From 9°C to 4°C	17 Jan, 1969	2.1	5.1	1.4	3.1
From 9°C to 4°C	28 Feb, 1969	3.0	4.3	3.4	2.9
Continuous 9°C	-	6.7	3.7	7.0	1.7
From 4°C to 9°C	6 Dec, 1968	6.3	3.5	10.9	1.1
From 4°C to 9°C	17 Jan, 1969	5.8	3.5	7.5	1.4
From 4°C to 9°C	28 Feb, 1969	3.1	2.0	4.8	1.2
Continuous 4°C	-	0.3	3.5	0.3	3.2

3. Rate of plant emergence. Average rates of plant emergence and associated blanking in relation to seed tuber disinfection and storage temperature treatment are shown in Table 26.

In 1970, there was no marked effect of storage temperature variation nor of tuber disinfection upon subsequent rate of emergence. In 1969, however, continuous storage at 4°C gave delayed emergence of both boxed, and boxed and disinfected tubers, compared with tubers transferred from 4°C to 9°C in December to February. Delayed emergence of untreated and disinfected tubers also occurred with transfer from 9°C to 4°C in early December, compared with tubers stored at 9°C until January or February or stored continuously at this temperature. In 1969, boxed and disinfected tubers, stored initially at 4°C before transfer to 9°C, tended to give slightly quicker emergence, compared with boxed, untreated tubers. Storage temperature and tuber disinfection had little effect upon percentage blanking which was low in both 1969 and 1970. Most blanking, however, tended to occur with boxed, untreated tubers, stored continuously at low temperature.

4. Tuber yield. Assessments of tuber number and weight yield in relation to seed tuber disinfection and storage temperature treatment are shown in Tables 27 and 28. In 1969, seed tubers stored continuously at 9°C gave higher tuber number and weight yields, compared with seed stored at 4°C. With varying periods of storage at different

Table 26. Rate of plant emergence and degree of blanking in relation to seed tuber disinfection and storage temperature treatments, (a) 1968-69, and (b) 1969-70.

Storage temperature treatment	Date of transfer	Average rate of emergence (days)		% Blanking	
		Boxed and disinfected	Boxed only	Boxed and disinfected	Boxed only
(a) 1968-69					
From 9°C to 4°C	6 Dec, 1968	36.1	36.6	0.0	0.0
From 9°C to 4°C	17 Jan, 1969	29.0	29.3	0.0	0.0
From 9°C to 4°C	28 Feb, 1969	29.1	27.1	1.0	0.0
Continuous 9°C	-	25.0	28.2	1.0	1.0
From 4°C to 9°C	6 Dec, 1968	26.0	27.0	2.1	0.0
From 4°C to 9°C	17 Jan, 1969	25.1	26.5	0.0	0.0
From 4°C to 9°C	28 Feb, 1969	25.5	27.4	0.0	0.0
Continuous 4°C	-	35.5	36.9	0.0	2.1
(b) 1969-70					
From 7°C to 5°C	26 Nov, 1969	35.5	36.5	0.0	0.0
From 7°C to 5°C	24 Dec, 1969	35.0	37.0	0.0	0.0
From 7°C to 5°C	21 Jan, 1970	35.2	35.2	0.0	0.0
From 7°C to 5°C	18 Feb, 1970	35.2	37.5	0.0	1.6
Continuous 7°C	-	35.0	35.2	0.0	0.0
From 5°C to 7°C	26 Nov, 1969	35.0	35.5	1.6	1.6
From 5°C to 7°C	24 Dec, 1969	35.0	35.2	0.0	1.6
From 5°C to 7°C	21 Jan, 1970	35.0	35.0	0.0	0.0
From 5°C to 7°C	18 Feb, 1970	35.0	35.5	0.0	0.0
Continuous 5°C	-	35.0	37.8	0.0	3.1

Table 27. Tuber number in relation to seed tuber disinfection and storage temperature treatments, (a) 1968-69, and (b) 1969-70 (1000s/acre).

Storage temperature treatment	Date of transfer	Boxed and disinfected				Boxed only			
		Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
(a) 1968-69	SE ±	3.9	11.3	7.2	12.5	2.8	6.2	8.4	13.9
From 9°C to 4°C	6 Dec, 1968	13.6	215.9	44.4	273.9	18.6	167.5	28.5	214.6
From 9°C to 4°C	17 Jan, 1969	8.4	221.6	55.7	285.6	20.1	201.9	38.0	260.1
From 9°C to 4°C	28 Feb, 1969	14.3	234.3	53.9	302.4	30.6	215.5	48.0	294.0
Continuous 9°C	-	21.3	213.2	50.0	284.5	22.2	211.4	46.9	280.4
From 4°C to 9°C	6 Dec, 1968	28.5	196.9	48.9	274.3	18.6	213.0	48.4	280.0
From 4°C to 9°C	17 Jan, 1969	22.2	237.7	58.2	318.0	24.0	174.7	42.6	241.3
From 4°C to 9°C	28 Feb, 1969	21.0	214.6	43.9	279.5	26.3	173.6	38.3	238.1
Continuous 4°C	-	10.2	202.6	35.5	248.3	21.5	162.3	28.3	212.1
(b) 1969-70	SE ±	5.0	10.7	16.4	21.4	3.5	7.6	11.6	15.1
From 7°C to 5°C	26 Nov, 1969	23.4	207.7	44.9	275.9	25.5	161.0	26.9	213.5
From 7°C to 5°C	24 Dec, 1969	20.4	188.9	37.4	246.7	25.8	167.8	42.4	236.1
From 7°C to 5°C	21 Jan, 1970	23.1	204.9	40.8	268.8	14.9	184.8	41.9	241.6
From 7°C to 5°C	18 Feb, 1970	21.1	192.3	49.6	263.0	22.4	175.0	39.4	236.9
Continuous 7°C	-	42.1	168.5	40.1	250.7	36.7	135.2	26.1	198.0
From 5°C to 7°C	26 Nov, 1969	48.2	132.5	25.1	205.9	42.4	127.1	28.5	198.0
From 5°C to 7°C	24 Dec, 1969	58.2	156.0	27.5	231.6	62.5	134.8	33.7	231.0
From 5°C to 7°C	21 Jan, 1970	39.7	181.0	35.3	256.0	55.7	167.2	30.2	253.0
From 5°C to 7°C	18 Feb, 1970	52.7	205.9	41.0	299.7	46.2	155.6	26.1	227.9
Continuous 5°C	-	37.8	156.3	50.6	244.6	25.8	151.9	29.9	207.7

Table 28. Tuber weight yield in relation to seed tuber disinfection and storage temperature treatments, (a) 1968-69, and (b) 1969-70 (tons/acre).

Storage temperature treatment	Date of transfer	Boxed and disinfected				Boxed only			
		Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
(a) 1968-69	SE ±	0.7	0.5	0.1	0.9	0.9	0.8	0.1	1.0
From 9°C to 4°C	6 Dec, 1968	2.3	14.1	0.9	17.3	3.3	11.9	0.7	15.6
From 9°C to 4°C	17 Jan, 1969	1.5	15.2	1.1	17.7	3.6	14.1	0.7	18.4
From 9°C to 4°C	28 Feb, 1969	2.5	16.2	1.0	19.6	5.3	15.9	1.1	22.2
Continuous 9°C	-	3.5	15.5	1.0	19.9	4.0	15.4	1.0	20.4
From 4°C to 9°C	6 Dec, 1968	4.4	14.3	0.9	19.6	3.3	15.3	1.0	19.5
From 4°C to 9°C	17 Jan, 1969	4.1	17.0	1.2	22.2	4.3	13.2	0.9	18.3
From 4°C to 9°C	28 Feb, 1969	3.6	15.2	0.8	19.5	4.6	12.5	0.8	17.9
Continuous 4°C	-	1.6	13.6	0.7	15.9	4.0	12.2	0.7	16.9
(b) 1969-70	SE ±	1.0	0.7	0.1	1.1	0.7	0.5	0.1	0.8
From 7°C to 5°C	26 Nov, 1969	3.6	15.2	0.8	19.5	4.2	11.5	0.5	16.3
From 7°C to 5°C	24 Dec, 1969	3.3	12.6	0.7	16.5	4.1	12.0	0.7	16.8
From 7°C to 5°C	21 Jan, 1970	3.9	13.4	0.7	18.1	4.4	12.7	0.8	16.0
From 7°C to 5°C	18 Feb, 1970	3.5	13.4	0.9	17.8	3.5	12.3	0.7	16.5
Continuous 7°C	-	7.8	12.2	0.8	20.8	6.4	10.3	0.5	16.7
From 5°C to 7°C	26 Nov, 1969	8.7	10.1	0.5	18.8	8.3	9.8	0.6	18.6
From 5°C to 7°C	24 Dec, 1969	10.4	11.5	0.5	22.4	13.1	10.6	0.7	24.3
From 5°C to 7°C	21 Jan, 1970	7.3	13.7	0.6	21.5	10.1	12.6	0.6	23.2
From 5°C to 7°C	18 Feb, 1970	7.6	14.4	0.8	22.8	8.3	11.5	0.5	20.3
Continuous 5°C	-	6.3	11.5	0.8	18.6	4.1	10.9	0.6	15.6

temperatures, extended storage at the higher temperature tended to give higher yields. In 1970, however, differences in tuber yields, in relation to different storage treatments, were not as consistent as those of 1969 but highest weight yields still tended to occur with longer storage at the higher temperature. Disinfected seed, compared with untreated seed stored at the same temperature, gave higher seed and total tuber numbers in both years. Seed weight yields were often lower. Total weight yield differences, between comparable untreated and disinfected seed treatments, were not consistent.

5. Subsequent skin spot infection. In both 1969 and 1970 there was no obvious relationship between storage temperature treatment of boxed, and boxed and disinfected seed tubers upon the skin spot infection of the subsequent crops (Table 29). However, lower levels of surface and eye infection tended to occur, in both years, with boxed and disinfected tubers, compared with boxed tubers only. It is not known why subsequent level of infection should be so low for boxed and disinfected seed tubers transferred from 5°C to 7°C and boxed seed tubers transferred from 7°C to 5°C on 24 December, 1969.

Discussion

The level of skin spot infection obtained from tubers boxed at lifting, in 1968, was reduced with storage at a temperature of 10°C compared with that where storage was at 4°C. Exposure to high temperatures would have encouraged drying of the tubers,

Table 29. Skin spot infection of the subsequent crop in relation to seed tuber disinfection and storage temperature treatments, (a) 1968-69, and (b) 1969-70.

Storage temperature treatment	Date of transfer	Boxed and disinfected		Boxed only	
		S.I.I.	E.I.I.	S.I.I.	E.I.I.
(a) 1968-69					
From 9°C to 4°C	6 Dec, 1968	6.9	42.5	14.1	74.2
From 9°C to 4°C	17 Jan, 1969	8.6	50.4	9.5	65.6
From 9°C to 4°C	28 Feb, 1969	6.9	35.0	15.9	75.0
Continuous 9°C	-	8.5	43.3	10.4	58.6
From 4°C to 9°C	6 Dec, 1968	12.0	58.9	9.4	58.3
From 4°C to 9°C	17 Jan, 1969	8.8	50.2	11.8	58.7
From 4°C to 9°C	28 Feb, 1969	9.1	37.1	13.7	59.3
Continuous 4°C	-	7.4	44.2	13.5	60.6
(b) 1969-70					
From 7°C to 5°C	26 Nov, 1969	6.4	55.4	5.5	56.8
From 7°C to 5°C	24 Dec, 1969	2.3	20.2	0.6	4.1
From 7°C to 5°C	21 Jan, 1970	3.7	20.8	6.3	51.5
From 7°C to 5°C	18 Feb, 1970	2.4	18.3	4.5	32.0
Continuous 7°C	-	2.3	12.6	3.7	32.6
From 5°C to 7°C	26 Nov, 1969	4.4	26.7	3.2	31.4
From 5°C to 7°C	24 Dec, 1969	0.5	1.4	3.5	22.3
From 5°C to 7°C	21 Jan, 1970	1.9	15.9	3.8	25.7
From 5°C to 7°C	18 Feb, 1970	2.1	24.5	3.4	40.0
Continuous 5°C	-	1.4	16.6	3.8	35.1

resulting in inhibition of fungal growth at the tuber surface. In 1969, when storage temperatures of 1-7°C and 5-13°C were compared, and in 1970 when storage temperatures of 3-7°C and 4-10°C were compared, different storage temperature treatments produced no differences in skin spot levels. Reduced infection, however, was found in 1969 and 1970 with boxed and disinfected tubers compared with boxed, untreated tubers.

The increased sprout lengths obtained, in 1969, with box storage of seed tubers at the higher temperature, was reflected in quicker rates of plant emergence and higher tuber yields of the subsequent crops. In 1969, greater numbers of sprouts per tuber were produced from disinfected seed than from untreated seed and increased tuber numbers generally occurred with boxed and disinfected seed under all conditions of storage temperature. Seed weight yields were greater from disinfected tubers than from untreated tubers but ware yield tended to be lower. From a comparison of skin spot levels of the crops after storage, somewhat lower levels of infection generally occurred in crops from disinfected seed than from untreated seed.

B_4 The effect of different fungicidal treatments of seed tubers at lifting upon level of skin spot infection after storage.

This experiment was designed to investigate the effects of various seed tuber disinfection treatments carried out at lifting, using different commercial fungicides, upon the level of skin spot infection after storage.

Materials and methods

In testing the effectiveness of various fungicidal treatments for the control of skin spot, King Edward seed tubers lifted on 17 October, 1967 and 24 October, 1968, were placed in standard, wooden, chitting trays and treated as follows, allowing two trays per treatment:-

1967

(a) Dipped in a solution of Aretan (ethoxyethyl-mercuric-chloride), (12 oz./15 gal., 150 ppm. Hg.), for 1 minute.

(b) Dipped in a solution of Aretan (12 oz./15 gal., 150 ppm. Hg.) plus wetter (Agral), for 1 minute.

(c) Dipped in a solution of Agallol (methoxyethyl-mercuric-chloride), (12 oz./15 gal., 150 ppm. Hg.), for 1 minute.

(d) Dipped in a solution of Boots RD 8684 (Quinazamid: 4-hydroxyphenylazoformamide), (4.8 oz./15 gal., 0.1% a.i.), for 1 minute.

(e) Dipped in a solution of Terrazole (5-ethoxy 3-Trichloromethyl 1, 2, 4-Thiozole), (0.4 pts./15 gal., 95%), for 1 minute.

(f) Dipped in a solution of Terrachlor super X (Pentachloro-nitrobenzene plus Terrazole), (6 pts./15 gal.), for 1 minute.

(g) Boxed, untreated.

Other tubers were clamped on the date of lifting as further, untreated controls (h).

1968 (A)

(a) Dipped in a solution of Aretan (12 oz./15 gal., 150 ppm. Hg.), prepared nine days previously, for 1 minute.

(b) Dipped in a solution of Aretan (12 oz./15 gal., 150 ppm. Hg.), prepared fresh, immediately before treatment, for 1 minute.

(c) Dipped in a solution of Agallol (12 oz./15 gal., 150 ppm. Hg.), prepared fresh, immediately before treatment, for 1 minute.

(d)-(i) Dipped in a range of solutions of MC 25 (Guazatine: 9-Aza-1, 17-diguanidinoheptadecane) of different concentrations, for varying times (See Table 30).

(j) Untreated, boxed.

Other tubers were clamped on the date of lifting as further, untreated controls (k).

All boxed treatments were removed to an insulated store and kept at approximately $4^{o}C$ until the following April when three random, 40-tuber samples were removed from all treatments, washed and assessed for skin spot development.

Following the release in 1968, of an experimental fungicide, 'Benlate' (Benomyl), by the Du Pont Company (U.K.) Ltd., its

effectiveness in the control of skin spot was compared with that of Agallol disinfected tubers in 1968 and 1969.

1968 (B) Seed size King Edward tubers, lifted in late October, were treated on 4 November, as follows:-

(a) Boxed and dipped in a solution of Agallol (8 oz./15 gal., 100 ppm. Hg.), for 12 minutes.

(b) Boxed and dipped in a solution of Benlate (2.4 oz./15 gal., 500 ppm.), plus 33 cm^3 surfactant F*, for 12 minutes.

(c) Boxed, untreated.

(d) Dusted with Benlate (8 oz./cwt., 10% a.i.), and stored in a plastic bin at high humidity.

(e) Untreated and stored in a plastic bin at high humidity.

Two boxes were used for each of treatments (a), (b) and (c) and one bin, containing 150 tubers, was used in each of treatments (d) and (e). All treatments were removed to an insulated store and held at approximately 4°C until April, 1969 when three random, 50-tuber samples were removed from all treatments, washed and assessed for skin spot development.

1969 King Edward seed tubers lifted on 22 October, were treated as follows:-

(a) Boxed and dipped in a solution of Agallol (12 oz./15 gal., 150 ppm. Hg.), for 1 minute.

(b)-(g) Boxed and dipped in a range of solutions of Benlate, of different concentrations, for varying times of tuber immersion (see Table 31).

(h)-(j) Boxed and sprayed with a range of solutions of Benlate, of different concentrations (Table 31).

*Du Pont Company (U.K.) Ltd.

Table 30. Skin spot infection in relation to various fungicidal treatments carried out at lifting, 1967 and 1968.

Fungicidal treatment		Skin spot infection	
		S.I.I.	E.I.I.
1967			
(a) Aretan (12 oz./15 gal., 150 ppm. Hg.)	1 min.	5.1	47.0
(b) Aretan (12 oz./15 gal., 150 ppm. Hg.) plus wetter	1 min.	6.1	72.0
(c) Agallol (12 oz./15 gal., 150 ppm. Hg.)	1 min.	3.5	39.0
(d) Boots RD 8684 (4.8 oz./15 gal., 0.1% a.i.)	1 min.	11.3	71.0
(e) Terrazole (0.4 pts./15 gal., 95%)	1 min.	9.4	63.0
(f) Terrachlor super X (6 pts./15 gal.)	1 min.	13.8	68.0
(g) Boxed, untreated		17.4	75.0
(h) Clamped, untreated		46.7	81.0
1968 (A)			
(a) Aretan (12 oz./15 gal., 150 ppm. Hg.), prepared nine days previously	1 min.	2.2	36.5
(b) Aretan (12 oz./15 gal., 150 ppm. Hg.), prepared fresh	1 min.	2.7	40.7
(c) Agallol (12 oz./15 gal., 150 ppm. Hg.), prepared fresh	1 min.	1.9	37.7
(d) MC 25 (36 oz./15 gal.)	1 min.	6.6	59.2
(e) MC 25 (36 oz./15 gal.)	5 min.	5.8	56.4
(f) MC 25 (36 oz./15 gal.)	10 min.	6.5	60.3
(g) MC 25 (18 oz./15 gal.)	1 min.	7.2	60.4
(h) MC 25 (18 oz./15 gal.)	5 min.	6.1	58.7
(i) MC 25 (18 oz./15 gal.)	10 min.	6.3	59.1
(j) Boxed, untreated		7.3	58.9
(k) Clamped, untreated		11.6	74.5

Table 31. Comparison of Agallol and Benlate effectiveness in the control of skin spot, 1968 and 1969.

Fungicidal treatment		Skin spot infection	
		S.I.I.	E.I.I.
1968 (B)			
(a) Agallol (8 oz./15 gal., 100 ppm. Hg.)	12 min.	1.2	17.4
(b) Benlate (2.4 oz./15 gal., 500 ppm), plus 33 cm^3 surfactant F	12 min.	2.7	18.3
(c) Boxed, untreated		4.0	21.6
(d) Benlate dust (8 oz./cwt., 10% a.i.), bin storage		1.5	12.9
(e) Untreated, bin storage		5.0	29.0
1969			
(a) Agallol (12 oz./15 gal., 150 ppm. Hg.)	1 min.	1.1	29.2
(b) Benlate (1.2 oz./15 gal., 250 ppm.)	1 min.	5.3	57.1
(c) Benlate (1.2 oz./15 gal., 250 ppm.)	10 min.	6.3	63.6
(d) Benlate (2.4 oz./15 gal., 500 ppm.)	1 min.	5.8	64.1
(e) Benlate (2.4 oz./15 gal., 500 ppm.)	10 min.	6.0	65.0
(f) Benlate (3.6 oz./15 gal., 750 ppm.)	1 min.	5.4	63.8
(g) Benlate (3.6 oz./15 gal., 750 ppm.)	10 min.	5.2	62.4
(h) Benlate spray (1.2 oz./15 gal., 250 ppm.)		4.2	52.5
(i) Benlate spray (2.4 oz./15 gal., 500 ppm.)		4.9	59.3
(j) Benlate spray (3.6 oz./15 gal., 750 ppm.)		4.3	47.9
(k) Boxed, untreated		7.7	72.4
(l) Benlate dust (8 oz./cwt., 10% a.i.), bin storage		3.5	47.1
(m) Untreated, bin storage		13.9	79.4
(n) Clamped, untreated		23.2	93.3
(o) Ex-clamp 28 October, 1969, Agallol (12 oz./15 gal., 150 ppm. Hg.) 1 min.	1. 35°C	1.5	37.6
	2. 52°C	0.7	21.3
	3. 68°C	0.8	26.8
(p) Ex-clamp 22 January, 1970, Agallol (12 oz./15 gal., 150 ppm. Hg.) 1 min.	1. 35°C	7.8	78.2
	2. 52°C	8.2	83.4
	3. 68°C	8.2	74.9

(k) Boxed, untreated.

(l) Dusted with Benlate (8 oz./cwt., 10% a.i.), and stored in a plastic bin at high humidity.

(m) Untreated and stored in a plastic bin at high humidity.

Other tubers were clamped on the date of lifting to act as further, untreated controls (n). In addition, tubers were removed from the clamp on 28 October, 1969 (o) and 22 January, 1970 (p) and 50-tuber samples were dipped in solutions of Agallol (12 oz./15 gal., 150 ppm. Hg.), for 1 minute, held at each of the following temperatures:- 35°C; 52°C and 68°C, and subsequently boxed.

Two boxes were used for each of treatments (a)-(k) and one bin, containing 150 tubers, was used in each of treatments (l) and (m). All boxed and bin treatments were removed to an insulated store and kept at approximately 4°C until late February, 1970, when three random, 40-tuber samples were removed from all treatments, washed and assessed for skin spot development.

Results

In both 1967 and 1968, boxing alone was shown to give a considerable reduction in level of skin spot infection, compared with clamp storage (Table 30). Much greater control, however, was obtained with Agallol, Aretan and Aretan plus wetter, in that order. Unaccountably, the addition of the wetter in 1967 gave no control of eye infection. There was no effect of time of preparation of the Aretan solution. Of the other treatments in 1967, only Terrazole, which has been used in the control of Rhizoctonia, gave a slight measure of control but it was inferior to the

organo-mercury disinfection. In 1968, none of the MC 25 treatments gave any further reduction than that obtained with boxing of the tubers alone.

In comparing the effectiveness of Agallol and Benlate disinfection of tubers in the control of skin spot in 1968 and 1969 (Table 31), Benlate, more especially as a dust treatment, gave a level of control equal to that of Agallol. In 1969, however, Agallol was somewhat more effective. In both years, Benlate dust was superior to Benlate dip and spray treatments. There was no marked differences in levels of control for different concentrations of Benlate solution, over the range used, nor for different periods of tuber immersion. The data does suggest, however, that the spray treatments, at all concentrations, are to be preferred to actual dipping of the tubers.

Removal of tubers from clamp storage in late October, followed by disinfection with Agallol solution also gave effective control of skin spot and it would appear that increasing the temperature of the solution, up to 52°C, improved the effectiveness of this treatment. Delaying similar treatment of clamped tubers until January, 1970, however, gave only a moderate level of control.

Discussion

Boxing of seed tubers at lifting was once again found to give some reduction in level of skin spot infection, compared with clamp storage. This, presumably, was the result of reduced humidity within the boxes, inhibiting the activity of *O. pustulans* upon the surface of the tubers. Much greater control, however, was achieved with boxing and disinfection in organo-mercury solutions, and of

the compounds used, Agallol proved to be most effective. The level of control obtained from Agallol disinfection was further improved where the temperature of the solution was increased to 52°C. Of the other, non-mercuric fungicides used, only the effect of Benlate disinfection was comparable with that of Agallol disinfection in reducing skin spot development. Generally, Benlate dust was more effective than either Benlate spray or dip treatments.

B_5 The effect of different fungicidal treatments of seed tubers at lifting or planting upon rate of emergence, yield and skin spot development of the subsequent crops.

In this experiment, tubers from certain of the fungicidal treatments carried out at lifting in Experiment B_4 along with, in two of the investigations, other comparable tubers subjected to various treatments at planting time, were planted in 1969 and 1970, and assessments made of rates of emergence, tuber yields and levels of skin spot infection of the subsequent crops.

Materials and methods

1968-69. From the series of treatments carried out at lifting in 1968, (A and B), the following treatments were selected for planting out in 1969:-

A (a) Boxed and dipped in a solution of Agallol (150 ppm. Hg.), for 1 minute.

(b) Boxed and dipped in a solution of MC 25 (36 oz./15 gal.), for 5 minutes.

(c) Boxed, untreated.

In addition, tubers from the same stock, stored in bags at 4°C from time of lifting, were treated just prior to planting as follows:-

(d) Boxed and dipped in a solution of Agallol (150 ppm. Hg.), for 12 minutes.

(e) Dusted with Benlate (8 oz./cwt., 10% a.i.).

(f) Boxed and dipped in a solution of Benlate (500 ppm.), for 12 minutes.

(g) Boxed and sprayed with a solution of Benlate (500 ppm.).

(h) Bagged, untreated.

B (a) Boxed and dipped in a solution of Agallol (100 ppm. Hg.), for 12 minutes.

(b) Boxed and dipped in a solution of Benlate (500 ppm.), plus Surfactant F*, for 12 minutes.

(c) Boxed, untreated.

(d) Dusted with Benlate (8 oz./cwt., 10% a.i.), and stored in a plastic bin at high humidity.

(e) Untreated, stored in a plastic bin at high humidity.

Tubers from all treatments were planted on 19 May, 1969, using plots of 16 tubers, at 11 in. spacing, in a randomised block layout with four and six replicates per treatment for A and B respectively.

1969-70. From tubers treated at lifting in 1969, the following treatments were selected for planting out in 1970:-

(a) Boxed and dipped in a solution of Agallol (150 ppm. Hg.), for 1 minute.

(b) and (c) Boxed and dipped in a solution of Benlate (500 ppm.), for different times of tuber immersion.

(d) Boxed and sprayed with a solution of Benlate (500 ppm.).

(e) Boxed, untreated.

(f) Dusted with Benlate (8 oz./cwt., 10% a.i.), and stored in a plastic bin at high humidity.

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(g) Untreated, stored in a plastic bin at high humidity.

(h) Ex-clamp 28 October, 1969, boxed and dipped in solutions of Agallol (150 ppm. Hg.), held at different temperatures, for 1 minute.

In addition, tubers from the same stock, clamped from time of lifting were treated just prior to planting as follows:-

(i) Boxed and dipped in a solution of Agallol (150 ppm. Hg.),for 1 minute.

(j) and (k) Boxed and dipped in a solution of Benlate (500 ppm.), for different times of tuber immersion.

(l) Boxed and sprayed with a solution of Benlate (500 ppm.).

(m) Dusted with Benlate (8 oz./cwt., 10% a.i.).

(n) Clamped, untreated.

Tubers from all treatments were planted on 7 May, 1970, in plots of 16 tubers, at 11 in. spacing, in a randomised block layout with four replicates per treatment.

In both 1969 and 1970, emergence counts were taken throughout the growing season until found constant and average rates of emergence calculated for all treatments. The haulms of all plants were cut on 29 September, 1969 and 15 September, 1970 and the crops lifted by elevator digger on 31 October and 30 September, respectively. The produce of each treatment was bagged and dressed out into ware, seed and chat yields in mid-December, 1969 and early October, 1970. Samples of the seed fractions of all

treatments were boxed and kept at approximately 4°C until mid-July, 1970 and April, 1971, when assessments of skin spot development were made.

Results.

1. Rate of plant emergence. Rates of plant emergence and percentage blanking in relation to different fungicidal treatments of seed tubers applied in 1968-69 and 1969-70 are shown in Tables 32 and 33.

Agallol disinfection of seed tubers at lifting had no effect upon rate of emergence or level of blanking in 1969 but in 1970, slightly earlier emergence and reduced blanking was obtained from disinfected seed, compared with boxed, untreated tubers. Where treatment was delayed for one week after lifting, in 1969, and Agallol solutions at varying temperatures were used, there was no advantage in emergence rate from the treatments, and emergence was delayed and blanking increased where the temperature of the dip was 68°C (Table 33). With Agallol disinfection at planting, emergence was delayed in 1969, compared with untreated tubers but in 1970, rates of emergence were similar for both disinfected and untreated tubers, although level of blanking was higher from disinfected seed.

Benlate disinfection of seed tubers at lifting tended to give improved emergence, compared with untreated tubers, the effect being most marked with Benlate dust treatment followed by tuber storage in plastic bins at high humidity. There was no effect of Benlate disinfection of tubers, just

Table 32. Rate of plant emergence and percentage blanking in relation to various fungicidal treatments of seed tubers, applied in 1968-69.

1969

Fungicidal treatment		Average rate of emergence (days)	% Blanking
A			
At lifting:-			
(a) Agallol (150 ppm. Hg.)	1 min.	36.6	0.0
(b) MC 25 (36 oz./15 gal.)	5 min.	42.1	3.2
(c) Boxed, untreated		37.2	0.0
At planting:-			
(d) Agallol (150 ppm. Hg.)	12 min.	43.2	0.0
(e) Benlate dust (8 oz./cwt., 10% a.i.)		38.2	0.0
(f) Benlate (500 ppm.)	12 min.	36.7	0.0
(g) Benlate spray (500 ppm.)		37.5	3.2
(h) Bagged, untreated		38.0	3.2
B			
At lifting:-			
(a) Agallol (100 ppm. Hg.)	12 min.	32.2	0.0
(b) Benlate (500 ppm.), plus 33 cm^3 surfactant F	12 min.	31.6	0.0
(c) Boxed, untreated		32.4	0.0
(d) Benlate dust (8 oz./cwt., 10% a.i.), bin storage		33.5	0.0
(e) Untreated, bin storage		37.8	0.0

Table 33. Rate of plant emergence and percentage blanking in relation to various fungicidal treatments of seed tubers, applied in 1969-70.

1970

Fungicidal treatment			Average rate of emergence (days)	% Blanking
At lifting:-				
(a) Agallol (150 ppm. Hg.)		1 min.	37.0	0.0
(b) Benlate (500 ppm.)		1 min.	37.8	0.0
(c) Benlate (500 ppm.)		10 min.	37.2	0.0
(d) Benlate spray (500 ppm.)			39.5	0.0
(e) Boxed, untreated			41.2	7.8
(f) Benlate dust (8 oz./cwt., 10% a.i.), bin storage			36.8	0.0
(g) Untreated, bin storage			40.0	6.2
(h) Ex-clamp 28 October, 1969, Agallol (150 ppm. Hg.), 1 min.	1.	35°C	40.2	1.6
	2.	52°C	40.0	0.0
	3.	68°C	46.5	12.5
At planting:-				
(i) Agallol (150 ppm. Hg.)		1 min.	39.5	14.1
(j) Benlate (500 ppm.)		1 min.	40.0	11.2
(k) Benlate (500 ppm.)		10 min.	39.0	6.2
(l) Benlate spray (500 ppm.)			38.8	7.8
(m) Benlate dust (8 oz./cwt., 10% a.i.)			42.2	15.6
(n) Clamped, untreated			39.2	7.8

prior to planting, upon rate of emergence and level of blanking except in 1970, when dust treatment delayed emergence and increased blanking, compared with untreated tubers. Variation in the period of tuber immersion in Benlate solution, either at time of lifting or planting, had no effect upon rate of emergence.

In 1969, MC 25 disinfection of tubers at lifting, resulted in delayed emergence and increased blanking, compared with boxed, untreated tubers.

2. Crop yield. Untreated, boxed tubers gave generally higher yields with greater tuber numbers compared with untreated tubers stored in bags, bins or clamps until planting time. Agallol disinfection at lifting, resulted in increased total tuber numbers in all experiments and increased weight yields in 1969(A) and 1970, compared with untreated, boxed tubers (Tables 34 and 35). In 1970, however, Agallol disinfection treatments using heated solutions, applied in late October, 1969, were found to depress tuber yields. The effects of Agallol disinfection at planting varied: in 1969(A), total tuber number from disinfected seed was slightly greater than from bagged, untreated tubers and total tuber weight yield was unaffected, but in 1970, both total tuber number and weight yields were lower for disinfected tubers, in comparison with clamped, untreated tubers.

Of the several Benlate disinfection treatments carried out at lifting, Benlate dust in both years, gave increased

Table 34. Tuber yield in relation to various fungicidal treatments of seed tubers, applied in 1968-69.

October 1969

Fungicidal treatment	Tuber yield (1000s/acre)				Tuber yield (tons/acre)			
	Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
A								
At lifting:-								
(a) Agallol (150 ppm. Hg.), 1 min.	22.4	207.1	41.8	271.3	3.6	16.1	0.8	20.5
(b) MC 25 (36 oz./15 gal.), 5 min.	22.4	141.6	21.0	185.0	4.2	10.7	0.4	15.3
(c) Boxed, untreated	19.4	166.8	18.3	204.5	3.4	13.6	0.4	17.4
At planting:-								
(d) Agallol (150 ppm. Hg.), 12 min.	13.6	175.2	29.2	218.0	2.3	13.3	0.5	16.1
(e) Benlate dust (8 oz./cwt., 10% a.i.)	12.0	203.0	40.7	255.7	2.4	13.9	0.6	16.9
(f) Benlate (500 ppm.), 12 min.	11.5	213.6	36.0	261.1	1.6	16.2	0.6	18.4
(g) Benlate spray (500 ppm.)	16.3	183.1	34.4	233.8	2.4	13.6	0.5	16.5
(h) Bagged, untreated	18.7	154.1	19.7	192.5	3.0	13.3	0.3	16.6
B								
At lifting:-								
(a) Agallol (100 ppm. Hg.), 12 min.	13.9	211.6	58.7	284.2	2.3	13.8	0.9	17.0
(b) Benlate (500 ppm.), plus 33 cm^3 surfactant F 12 min.	8.1	205.7	50.9	264.7	1.1	14.0	0.8	15.9
(c) Boxed, untreated	10.5	228.4	32.2	271.1	1.7	15.4	0.5	17.6
(d) Benlate dust (8 oz./cwt., 10% a.i.), bin storage	12.9	209.5	53.0	275.4	2.1	15.2	0.9	18.2
(e) Untreated, bin storage	10.5	202.6	43.7	256.8	1.5	13.5	0.7	15.7
SE ±	3.4	8.9	3.8	12.9	0.9	0.7	0.1	0.9

Table 35. Tuber yield in relation to various fungicidal treatments of seed tubers, applied in 1969-70.

October 1970

Fungicidal treatment	Tuber yield (1000s/acre)				Tuber yield (tons/acre)			
	Ware	Seed	Chats	Total	Ware	Seed	Chats	Total
At lifting:-								
(a) Agallol (150 ppm. Hg.), 1 min.	42.8	183.5	43.2	269.5	7.3	13.1	0.8	21.2
(b) Benlate (500 ppm.), 1 min.	44.2	152.5	29.9	226.5	8.3	11.7	0.5	20.5
(c) Benlate (500 ppm.), 10 min.	54.1	151.5	44.6	250.2	10.2	11.0	0.8	22.1
(d) Benlate spray (500 ppm.)	41.0	136.2	40.5	217.7	7.7	10.6	0.7	19.0
(e) Boxed, untreated	38.1	146.8	29.6	214.5	6.9	10.9	0.6	18.5
(f) Benlate dust (8 oz./cwt., 10% a.i.), bin storage	36.4	191.9	53.3	281.6	5.6	14.0	1.0	20.6
(g) Untreated, bin storage	32.9	149.5	46.2	228.6	5.6	11.1	0.9	17.7
(h) Ex-clamp 28 October, 1969, Agallol (150 ppm. Hg.), 1 min.								
1. 35°C	20.7	148.1	34.7	203.4	4.1	10.9	0.6	15.7
2. 52°C	25.5	127.7	31.0	184.3	4.3	9.7	0.6	14.6
3. 68°C	16.3	126.1	35.6	178.0	2.8	8.9	0.7	12.4
At planting:-								
(i) Agallol (150 ppm. Hg.), 1 min.	24.2	129.1	28.3	181.6	4.2	9.7	0.6	14.6
(j) Benlate (500 ppm.), 1 min.	39.7	126.7	25.8	192.5	7.5	9.7	0.5	17.7
(k) Benlate (500 ppm.), 10 min.	29.9	157.4	30.6	217.8	5.6	11.4	0.6	17.5
(l) Benlate spray (500 ppm.)	32.3	123.9	32.6	188.9	6.1	9.2	0.6	15.8
(m) Benlate dust (8 oz./cwt., 10% a.i.)	22.8	137.5	32.9	193.2	4.5	10.2	0.5	15.2
(n) Clamped, untreated	32.9	129.4	33.7	196.0	6.6	9.9	0.6	17.1
SE ±	4.8	13.4	4.6	14.2	1.0	1.0	0.1	1.1

total tuber number and tuber weight yields, compared with boxed, untreated tubers. Disinfection by dipping at lifting, however, gave slightly reduced total tuber number and reduced weight yields, compared with boxed, untreated tubers, in 1969 but, increased tuber numbers and weight yields in 1970. Disinfection by spraying showed no effect on either tuber number or tuber weight, compared with untreated tubers. Benlate disinfection at planting had no consistent effect upon tuber yield production. Higher total tuber numbers occurred with all Benlate treatments in 1969 in comparison with untreated tubers but in 1970, tuber numbers were generally similar. Benlate dip treatment enhanced weight yield in 1969 but spray and dust treatments depressed yield in 1970. There were no differences, from different periods of tuber immersion in Benlate solution, upon tuber weight yield, either when treatment was applied at time of lifting or planting of seed tubers, but increased tuber numbers were obtained with increased period of immersion.

In 1969, MC 25 disinfection of seed tubers at lifting gave decreased total tuber number and weight yields compared with boxed, untreated tubers.

3. Skin spot development of subsequent crop. Assessments of skin spot infection of the subsequent crops after storage, made in 1970 and 1971, in relation to various fungicidal treatments of seed tubers, applied in 1968-69 and 1969-70, are shown in Tables 36 and 37. In both years, only moderate levels of skin spot tended to develop on the produce from untreated tubers and in general there was no marked reduction

Table 36. Skin spot infection of the subsequent crop in relation to various fungicidal treatments of seed tubers, applied in 1968-69.

July 1970

Fungicidal treatment		Skin spot infection	
		S.I.I.	E.I.I.
A			
At lifting:-			
(a) Agallol (150 ppm. Hg.)	1 min.	6.7	43.9
(b) MC 25 (36 oz./15 gal.)	5 min.	6.3	47.1
(c) Boxed, untreated		7.1	50.0
At planting:-			
(d) Agallol (150 ppm. Hg.)	12 min.	6.1	41.6
(e) Benlate dust (8 oz./cwt., 10% a.i.)		4.8	23.3
(f) Benlate (500 ppm.)	12 min.	6.5	41.8
(g) Benlate spray (500 ppm.)		7.4	47.6
(h) Bagged, untreated		7.8	60.2
B			
At lifting:-			
(a) Agallol (100 ppm. Hg.)	12 min.	3.4	15.0
(b) Benlate (500 ppm.), plus 33 cm^3 surfactant F	12 min.	5.1	30.0
(c) Boxed, untreated		6.2	35.9
(d) Benlate dust (8 oz./cwt., 10% a.i.), bin storage		3.5	2.0
(e) Untreated, bin storage		5.3	27.6

Table 37. Skin spot infection of the subsequent crop in relation to various fungicidal treatments of seed tubers, applied in 1969-70.

April 1971

Fungicidal treatment		Skin spot infection	
		S.I.I.	E.I.I.
At lifting:-			
(a) Agallol (150 ppm. Hg.)	1 min.	1.8	7.7
(b) Benlate (500 ppm.)	1 min.	0.6	6.1
(c) Benlate (500 ppm.)	10 min.	0.8	7.3
(d) Benlate spray (500 ppm.)		1.1	4.7
(e) Boxed, untreated		1.2	6.3
(f) Benlate dust (8 oz./cwt., 10% a.i.), bin storage		1.6	5.6
(g) Untreated, bin storage		2.7	16.3
(h) Ex-clamp 28 October, 1969 Agallol (150 ppm. Hg.), 1 min.	1. 35°C	1.0	4.2
	2. 52°C	3.3	15.8
	3. 68°C	0.3	3.7
At planting:-			
(i) Agallol (150 ppm. Hg.)	1 min.	1.0	2.1
(j) Benlate (500 ppm.)	1 min.	6.2	37.9
(k) Benlate (500 ppm.)	10 min.	6.8	38.5
(l) Benlate spray (500 ppm.)		6.5	53.7
(m) Benlate dust (8 oz./cwt., 10% a.i.)		0.2	2.0
(n) Clamped, untreated		6.8	47.5

in infection from any of the disinfection treatments. However, slightly less disease development was associated with Benlate dust treatments and, in 1970(B), with Agallol disinfection treatment, when applied at lifting of the seed tubers, in comparison with untreated, boxed tubers. With disinfection at planting, Benlate dust treatment again proved most effective in reducing skin spot infection although in 1971, Agallol disinfection also gave reduced infection, compared with untreated tubers. There was no effect of Benlate dip or spray treatments, when applied at either time of lifting or planting of seed tubers, nor of MC 25 disinfection upon subsequent skin spot development. Different temperatures of Agallol solution treatments, (Table 37), showed no consistent differences in the results.

Discussion

Both Agallol and Benlate disinfection of seed tubers, applied at time of lifting, gave slightly earlier plant emergence and reduced blanking in some cases, compared with untreated tubers. Where Agallol disinfection was delayed until six days from lifting and carried out at different temperatures of solution, a marked delay in emergence and increased blanking was found with disinfection at 68°C. There was no consistent effect of Agallol or Benlate disinfection of seed tubers, at planting, upon plant emergence or level of blanking.

Agallol disinfection of seed tubers at lifting was found to result in increased total tuber number and weight yields of the crop, compared with untreated tubers. With increased temperature

of disinfection, however, tuber yields were markedly lower. Of the Benlate disinfection treatments applied at lifting, only Benlate dust gave consistently increased tuber number and weight yields. The effect upon crop yield of Agallol or Benlate disinfection, when applied at planting, varied, and yield depressions were associated with Agallol and certain Benlate treatments in 1970.

Skin spot infection of the subsequent crops tended to be low in both 1970 and 1971 and generally there was no marked reduction in infection from any of the disinfection treatments, compared with untreated tubers. However, some reduction was afforded with Benlate dust and to a lesser extent, Agallol disinfection, when applied at either lifting or planting of the seed tubers. There was no effect of Benlate dip or spray treatment upon subsequent skin spot development.

DISCUSSION

Time of haulm destruction was found to have no consistent effect upon subsequent skin spot development, while tuber yield may increase with delay in haulm destruction over the period late August to late September, where favourable growing conditions prevail. With delay in lifting over the same period, however, the level of skin spot development of clamped, boxed, and, to a lesser extent, boxed and organo-mercury disinfected tubers, was found to increase. At all times of lifting, some control of surface infection was obtained with boxing, compared with clamping tubers, but the most effective level of control of skin spot infection was obtained with boxing and disinfection in an organo-mercury solution. After varying periods of clamp storage, following lifting in October, boxing alone gave only a slight measure of disease control, while the effectiveness of disinfection treatment declined with delay in the time of application.

These results would indicate that there was a progressive development of tuber infection in the field and that this development could be reduced, in its early stage, by boxing alone. This check in fungal activity by boxing might be attributed to exposure of the tubers to dry conditions, compared with the damp conditions of clamp storage or of the soil. The reduced effectiveness of boxing in controlling skin spot development at later times of lifting, may be attributed to the establishment of the pathogen in the tuber tissues having reached a stage that it could no longer be checked by changing humidity; or to lower ambient temperatures at later lifting times, rendering the boxing treatment less effective.

Evidence of the importance of temperature upon skin spot infection of boxed tubers was afforded by tuber storage under varying conditions of storage temperature. Reduced levels of infection were obtained with extended storage of boxed tubers at higher temperatures (10°C), compared with storage at lower temperatures (4°C). With delay in applying treatments after normal lifting time, up to a period of four to six weeks, a reasonable reduction in disease level could be achieved by boxing and organo-mercury disinfection. The failure of such treatment to effectively control skin spot infection after this period of clamp storage, following normal lifting, was attributed to the inability of the organo-mercury solution to penetrate to the depth of tuber tissue at which the fungus had become established, as a result of exposure to favourable conditions of growth during clamp storage.

Boxing and organo-mercury disinfection of tubers stimulated sprout growth and was generally found to give improved plant emergence and increased tuber numbers and weight yields, associated particularly with higher yields of the seed fractions. In some cases, however, ware yields were greater from untreated than from disinfected seed tubers and total weight yields were similar. Other workers have reported similar effects of organo-mercury disinfection of seed tubers at lifting upon subsequent crop growth (Boyd, 1960; McGee, 1967; Penna, 1970). General stimulation of crop growth was also obtained with extended box storage of tubers at relatively high temperatures and where boxed tubers were stored at 9°C, there was no yield advantage from organo-mercury disinfection, in comparison with untreated tubers.

Of various fungicides tested for the control of skin spot, only Benlate, particularly Benlate dust, gave as effective control as organo-mercury disinfection of seed tubers. Both organo-mercury and Benlate dust disinfection were found to give improved emergence and increased tuber yields, compared with untreated tubers, when applied at lifting but not at time of planting. In addition, particularly Benlate, appeared to have some carry-over effect, when applied either at time of lifting or of planting, since slightly lower levels of infection of the subsequent crop were associated with boxed and disinfected, compared with untreated seed tubers.

GENERAL DISCUSSION

A knowledge of the sources of spread and means of survival of O. pustulans is important as a basis for an approach to the control of skin spot disease of potatoes. The results of this work indicate that the carry-over of the fungus on seed tubers forms the major source of skin spot infection of crops. From studies on the pattern of colonisation by the fungus of the underground stem parts, the most heavily infected areas were generally found upon the lower regions of the stems and on the lower stolons, i.e. at positions nearest to the seed tuber. On the stolons, higher levels of infection were found on regions near their points of attachment to the stem than at their distal ends. The more heavily infected parts are presumably nearer the source of inoculum and the pattern of distribution suggests that the fungus spreads from the seed tuber to the progeny tubers mainly via the stems and stolons. Infection of the underground parts is confined to the cortex (Hirst and Salt, 1959), and is distributed in patches with no evidence of any systemic spread of O. pustulans: the fungus would thus appear to be carried to the progeny tubers by means of superficial infection and contamination of extension growth, lesions on the stem bases and stolons forming further sources of inoculum for tuber infection. Boyd (1957), has observed that skin spot pustules are frequently found around the stolon scar at the heel end of the tuber. This again suggests a passage of the organism via the underground stem parts to the crop. It was also found that the level of infection of stem bases and stolons and the amounts of disease

in the subsequent crop were related to the seed infection category, in keeping with the findings of Boyd and Lennard (1961a) and Hirst et al (1966, 1973); more severely infected seed associated with a higher level of inoculum, generally giving higher levels of subsequent crop infection.

In comparing the relative importance of tuber-borne and soil-borne inoculum, soil-borne transmission appears to be of little significance in influencing the general incidence of the disease. In a seed tuber survey carried out in the years 1963 to 1970, Hirst et al (1970), showed that O. pustulans is very common on seed tubers, and considered that there was no direct evidence that the fungus can grow for long in soils. In the present work, studies on O. pustulans infection of underground parts of potato plants grown in soil to which inoculum had been added, showed that the pattern of colonisation associated with seed as a source of infection, as previously described, was unaltered by the presence of added soil inoculum. In investigations on the overwintering of O. pustulans, in various sterilised and unsterilised soils, it was found that the organism could persist over a period of one to two years, but at only low levels: the level of recovery, as measured by the level of infection of tomato roots, was only appreciable over this period in sterilised soils, i.e. in the absence of competition from other soil micro-organisms. Hide (1970), however, has found a few microsclerotia of the fungus able to produce spores after seven years burial in soils. Thus, although soil-borne inoculum appears to be relatively unimportant in the general epidemiology of the disease the persistence of O. pustulans in soils, even at low levels, may be

of significance in the initial contamination of skin spot-free seed stocks derived from stem cutting material. Once seed stocks become contaminated, the fungus may multiply rapidly over one or two seasons during growth: i.e. contaminated tubers which are visibly free from infection may give slight levels of infection in progeny tubers which in turn, are capable of giving rise to severe levels of disease in the next crop. Secondary spread of spores of the fungus may also occur in storage (Edie, 1966).

Although soil inoculum appears to have little effect on the general incidence of skin spot, soil type was found to have an influence upon the level of transmission and development of the disease. Greater levels of colonisation of stems and stolons, and of skin spot infection of the subsequent crop, occurred with heavy, clay soils than with light, sandy soils. Boyd and Lennard (1961a), found high levels of skin spot infection were associated with high levels of soil moisture around time of lifting and the effect of soil type may be related, in part, to the relative ability of different soils to retain moisture. The importance of soil moisture, in relation to skin spot development, was confirmed by studies investigating the effect of adding different amounts of water to a soil during the later stages of crop growth. Increased levels of skin spot infection were obtained with increased total volume of water applied. In addition, skin spot development from soils within the same texture group was found to differ with differences in the proportion of stones greater than 2.0 mm. present: this would affect the permeability of the soils to water. The general relationship between soil type and skin spot development was in accordance

with that found by Salt (1964), higher infection was associated with heavy, loam than with sandy, light loam soils. In addition to its possible effect on the activity of the fungus, a further influence of soil type on level of infection may be attributed to its effect on rate of plant growth. Rates of growth, as evidenced by plant emergence rates, were more rapid in lighter soils: more rapid extension growth may have allowed less contamination of the underground parts as they grew away from seed inoculum.

The effects of level of seed infection upon plant emergence and crop yield were similar to those found by Boyd and Lennard (1961a) and Hirst, Hide and Stedman (1965, 1966, 1967 and 1973). Increase in level of seed infection was found to result in delayed rates of plant emergence, increased blanking and a reduction in the number of main stems produced per tuber. The number of tubers produced was less with higher levels of seed infection. When a crop was planted for ware purposes, i.e. at about 16 in., corresponding reductions in total tuber weight yields were also obtained. It may be noted, however, that Hide et al (1969), have indicated that the production of high tuber numbers from healthier seed stocks may not necessarily benefit ware yields, inasmuch as tuber size tends to decrease. With a seed crop spacing (11 in.), compensatory growth of adjacent plants may offset the adverse effects of skin spot infection on growth from seed tubers: total yields may not be affected, a reduction in seed yield being offset by an increase in ware yield. Such changes in the proportion of ware to seed fractions would, of course, be undesirable in a crop to be grown for seed purposes.

Rates of plant emergence, level of blanking and tuber yield were also affected by soil type. The generally higher temperatures associated with light soils, enabled the tuber sprouts, by more rapid extension, to overcome the effects of skin spot eye infection, and more rapid plant emergence, less blanking and higher tuber yields were associated with light, sandy soils compared with heavy, clay soils.

Of the factors, at lifting, investigated in relation to the control of skin spot, time of haulm destruction was found to have no effect upon subsequent skin spot development. Time of lifting, however, was found to influence the disease level, higher subsequent levels of infection occurring with delayed lifting. Boxing of tubers at lifting gave satisfactory measure of control but only where lifting was carried out early. With later times of lifting, a high degree of control was achieved only with boxing and organo-mercury disinfection of tubers. When boxing treatments were delayed until after clamp storage following lifting, boxing and disinfection and, to a much less extent, boxing only, gave some control compared with clamped tubers but the effectiveness of these treatments decreased with delay in application until six weeks after lifting. These findings are in accordance with those of Boyd (1959) and McGee (1967).

Variation of storage temperature was found to affect skin spot development in that prolonged storage of tubers at high temperature (9°C), gave reduced levels of disease development.

As reported by Boyd (1960), McGee (1967) and Penna (1970), boxing and organo-mercury disinfection of tubers at lifting, was

generally found to result in more rapid plant emergence, less blanking and increased tuber numbers, and in some cases, higher weight yields, more especially seed yields, compared with untreated tubers. Yield advantages of a similar order, however, were obtained from boxed tubers without disinfection, stored at high temperature (9°C).

Attempts to find satisfactory alternatives to organo-mercury disinfection for the control of skin spot, showed that of those fungicides tested, only Benlate could compare favourably with the effect of organo-mercury compounds. Both organo-mercury and Benlate dust disinfection were found to give improved emergence and in some instances, increased tuber yields, compared with untreated seed tubers, but only when applied at lifting. A slight reduction in subsequent disease development was obtained in crops from boxed and disinfected seed tubers, when compared with untreated tubers. Benlate dust, when applied at lifting or planting was found to give a slightly greater reduction in the level of carry-over, than organo-mercury disinfection. No studies were carried out with 2-amino butane (sec-butylamine), which is shown to give very effective control of skin spot (Graham and Hamilton, 1970).

In a general consideration of the control of skin spot, stocks derived from stem cutting material, while providing freedom from disease in the initial stages of multiplication, are liable to become contaminated and it would seem that the complimentary use of an effective fungicide would be necessary to maintain healthy stocks.

REFERENCES

1. ALLEN, J. D. (1957):

The development of potato skin spot disease. Ann. appl. Biol. 45, 293-298.

2. ANON, (1932):

Skin spot and blindness in seed potatoes. Scot. J. Agric. 15, 191-196.

3. BOYD, A. E. W. (1954):

Blanking in potato crops. Scot. J. Agric., 34, 86-89.

4. BOYD, A. E. W. (1957):

Field experiments on potato skin spot disease caused by Oospora pustulans Owen and Wakef. Ann. appl. Biol. 45, 284-292.

5. BOYD, A. E. W. (1960):

Fungicidal dipping and other treatments of seed potatoes in Scotland. Eur. Potato J., 3, 137-154.

6. BOYD, A. E. W. and LENNARD, J. H. (1961a):

Some effects of potato skin spot (Oospora pustulans) in Scotland. Eur. Potato J., 4, 361-377.

7. BOYD, A. E. W. and LENNARD, J. H. (1961b):

Potato skin spot - a seed grower's problem. The Seed Potato (J. Nat. Ass. Seed Potato Merch.), 1, 9-12.

8. BOYD, A. E. W. and LENNARD, J. H. (1962):

Seasonal fluctuation in potato skin spot. Plant Path. 11, 161-166.

9. CARRUTHERS, W. (1904):

Annual report of Botanist. J. R. Agric. Soc. 65, 261-262.

10. EDIE, H. H. (1964):

Some aspects of skin spot (Oospora pustulans) infection of the potato crop. M.Sc. Dissertation, University of Edinburgh.

11. EDIE, H. H. (1966):

Skin spot (Oospora pustulans) - its possible spread in storage. Eur. Potato J., 9, 161-164.

12. EDIE, H. H. and BOYD, A. E. W. (1966):

The effect of delay in treatment on the control of potato skin spot (Oospora pustulans). Eur. Potato J., 9, 216-255.

13. FOISTER, C. E. (1943):

On the control of skin spot disease of potato. Ann. appl. Biol. 30, 186-187.

14. FUCHS, W. H. (1954):

Einige Beobachtungen uber die Pickelbildung (Tupfelfleckigkeit) der Kartoffel. Nachr. Bl. Dtsch. PflSch. Dienst (Braunschw.) Stuttgart, 6, 75-76.

15. GOMOLYAKO, L. G. (1959):

The effect of oosporosis disease on the chemical composition of the potato tuber. Biokhim. Plod. Ovoshsch., 5, 159-164 (R.A.M., 39, 189).

16. GRAHAM, D. C. and HAMILTON, G. A. (1970):

Control of potato gangrene and skin spot diseases by fumigation of tubers with Sec-butylamine. Nature 227, 297-298.

17. GREEVES, T. M. and MUSKETT, A. E. (1939):

Skin spot of the potato and its control by tuber disinfection. Ann. appl. Biol. 26, 481-496.

18. GUSSOW, H. T. (1918):

Observations on obscure potato troubles. II. Unfavourable storage conditions. Phytopathology, 8, 492-493.

19. HAMILTON, G. A. and RUTHVEN, A. D. (1967):

Residual mercury content of seed potatoes treated with organo-mercury disinfectant solutions. J. Sci. Fd. Agric. 18, 558-563.

20. HIDE, G. A. (1968):

Ann. Rep. Rothamsted Exp. Sta. 1967, 132.

21. HIDE, G. A. (1970):

The occurrence, development and control of skin spot (Oospora pustulans) disease of potatoes. Ph.D. Thesis, University of London.

22. HIDE, G. A., HIRST, J. M. and GRIFFITH, R. L. (1969):

Control of potato tuber diseases with systemmic fungicides. Proc. 5th Br. Insectic. Fungic. Conf. 310-315.

23. HIDE, G. A., HIRST, J. M. and SALT, G. A. (1968):

Methods of measuring the prevalence of Pathogenic fungi on potato tubers. Ann. appl. Biol. 62, 309.

24. HIDE, G. A., HIRST, J. M. and STEDMAN, O. J. (1973):

Effects of skin spot (Oospora pustulans) on potatoes. Ann. appl. Biol. 73, 151-162.

25. HIRST, J. M. (1967):

The importance of tuber disease. Proc. 4th Br. Insectic Fungic. Conf. 1967, 547-555.

26. HIRST, J. M. et al (1967):

Ann. Rep. Rothamsted Exp. Sta. 1966, 128.

27. HIRST, J. M. and HIDE, G. A. (1964):

Ann. Rep. Rothamsted Exp. Sta. 1963, 113.

28. HIRST, J. M., HIDE, G. A., GRIFFITH, R. L. and STEDMAN, O. J. (1970):

Improving the health of seed potatoes. J. of the Roy. Agric. Soc. of England, 131, 87-106.

29. HIRST, J. M., HIDE, G. A. and STEDMAN, O. J. (1965):

Ann. Rep. Rothamsted Exp. Sta. 1964, 138.

30. HIRST, J. M., HIDE, G. A. and STEDMAN, O. J. (1966):

Ann. Rep. Rothamsted Exp. Sta. 1965, 132.

31. HIRST, J. M., HIDE, G. A., STEDMAN, O. J. and GRIFFITH, R. L. (1973):

Yield compensation in gappy potato crops and methods to measure effects of fungi pathogenic on seed tubers. Ann. appl. Biol. 73, 143-150.

32. HIRST, J. M. and SALT, G. A. (1956):

Ann. Rep. Rothamsted Exp. Sta. 1955, 105-106.

33. HIRST, J. M. and SALT, G. A. (1959):

Oospora pustulans Owen and Wakef. as a parasite of potato root systems. Trans. Brit. mycol. Soc. 42, 59-66.

34. HIRST, J. M., SALT, G. A. and HIDE, G. A. (1963):

Ann. Rep. Rothamsted Exp. Sta. 1962, 120-121.

35. IVES, J. V. (1955):

An abnormal form of skin spot on potatoes. Plant. Path. 4, 17-21.

36. JOHNSTON, J. F. W. (1845):

The potato disease in Scotland. No. 6, 185-186, quoted by Moore, W. C., 1959. British Parasitic Fungi. Cambridge Univ. Press.

37. KHARKOVA, A. P. (1961a):

On the biology of the causal agent of oosporosis - Oospora pustulans Owen and Wakef. Bot. Zh. S.S.S.R., 46, 399-407.

38. KHARKOVA, A. P. (1961b):

Influence of various factors on the behaviour of the fungus Oospora pustulans Owen and Wakef. and the susceptibility of potato to oosporosis. Bot. Zh. S.S.S.R., 46, 1508-1516.

39. KHROBRYKH, N. D. (1959):

Oosporosis in potato varieties and species. Bull. appl. Bot. Pl.-Breed., 33, 231-241 (R.A.M., 39, 343).

40. LENNARD, J. H. (1967):

The development of skin spot in relation to lifting and storage factors. Proc. 4th Br. Insectic. Fungic. Conf. 1967, 269-275.

41. LENNARD, J. H. and BOYD, A. E. W. (1964):

Production of sclerotia in Oospora pustulans. Expl. Wk. Edinb. Sch. Agric., 1964, 18.

42. McGEE, D. C. (1967):

Factors involved in the incidence of potato skin spot and in infection by the causal organism Oospora pustulans. Ph.D. Thesis, University of Edinburgh.

43. MILBURN, T. and BESSEY, E. S. (1915):

Fungoid diseases of farm and garden crops, pp. 90-91.

44. MILLARD, W. A. and BURR, S. (1923):

The causative organism of skin spot of potatoes. Kew Bull. No. 8, 273-287.

45. MILTHORPE, F. L. and MOORBY, J. (1966):
The growth of the potato. Proc. 3rd Trien. Conf. Europn. Assocn. potato research, 1966, 51-70.

46. MOORE, W. C. (1959):
Oospora pustulans. Bri. Paras. Fungi., 224-225.

47. NAGDY, G. A. (1962):
The mechanism of infection of potatoes by Oospora pustulans causing skin spot. Ph.D. Thesis, University of Edinburgh.

48. NAGDY, G. A. and BOYD, A. E. W. (1965):
Susceptibility of potato varieties to skin spot (Oospora pustulans) in relation to the structure of the skin and eye. Eur. Potato J. 8, 200-214.

49. O'BRIEN, D. G. (1919):
Rhizoctonia disease, or stem rot on potatoes. Scot. J. Agric., 2, 482-491.

50. OWEN, M. N. (1919):
The skin spot disease of potato tubers (Oospora pustulans). Kew Bull. No. 8, 289-301.

51. PENNA, R. J. (1969):
Studies on the disinfection of seed potatoes. Ph.D. Thesis, University of Edinburgh.

52. PETHYBRIDGE, G. H. (1915):
Investigations on potato diseases. J. Dept. Agric. Ire. 15, 524.

53. SALT, G. A. (1957):
Ann. Rep. Rothamsted Exp. Sta. 1956, 112-113.

54. SALT, G. A. (1958):
Ann. Rep. Rothamsted Exp. Sta. 1957, 116-117.

55. SALT, G. A. (1964):

The incidence of Oospora pustulans on potato plants in different soils. Plant Path. 13, 155-158.

56. SHAPOVALOV, M. (1923):

Relation of potato skin spot to powdery scab. J. Agric. Res. 23, 285-292.

57. TOOSEY, R. D. (1964):

The pre-sprouting of seed potatoes. Factors affecting sprout growth and subsequent yield. Part II. Fld. Crop Abstr. 17, 239-244.

58. WOLLENWEBER, H. W. (1920):

Der kartoffelschorf. III. Die pustelfaule. In Arb. Forschungs-inst. Kartoffelbau Heft 2, 73-74, Fig. 9. Quoted by Shapovalov, M. (1923).

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Appendix I Stem number per plant in relation to level of seed infection and time of harvest, 1968 and 1969.

(a) Loamy sand soil.

Date of lifting	Level of seed infection	Total stems above ground		Main stems		Lateral stems	
		1968	1969	1968	1969	1968	1969
July	Free	9.9	11.3	7.3	6.4	2.6	4.9
	Slight, some eyes	11.5	9.9	4.8	5.8	6.7	4.1
	Moderate-severe, all eyes	12.0	3.8	2.2	2.4	9.8	1.4
	SE ±	0.9	1.9	0.7	0.6	0.8	1.2
August	Free	9.0	12.3	6.9	5.4	2.1	6.9
	Slight, some eyes	8.2	13.7	3.9	4.8	4.3	8.9
	Moderate-severe, all eyes	6.4	18.6	2.7	5.3	3.7	13.3
	SE ±	0.8	1.7	0.4	0.8	0.8	1.6
September	Free	10.2	12.1	7.4	5.8	2.8	6.3
	Slight, some eyes	7.1	14.4	5.7	6.0	1.4	8.4
	Moderate-severe, all eyes	7.9	15.5	3.4	3.5	4.5	12.0
	SE ±	1.2	1.6	0.6	0.7	0.9	1.4
October	Free	8.9	11.4	8.2	5.5	0.7	5.9
	Slight, some eyes	5.5	15.3	4.3	5.5	1.2	9.8
	Moderate-severe, all eyes	5.9	20.9	3.5	4.4	2.4	16.5
	SE ±	0.5	2.4	0.7	1.3	0.3	1.9
AVERAGE	Free	9.6	11.8	7.5	5.8	2.1	6.0
	Slight, some eyes	8.1	13.3	4.7	5.5	3.4	7.8
	Moderate-severe, all eyes	8.1	14.7	3.0	3.9	5.1	10.8

(b) Boghall sandy clay-loam soil.

Date of lifting	Level of seed infection	Total stems above ground		Main stems		Lateral stems	
		1968	1969	1968	1969	1968	1969
July	Free	7.8	8.2	6.0	5.9	1.8	2.3
	Slight, some eyes	6.3	7.3	4.2	4.9	2.1	2.4
	Moderate-severe, all eyes	5.6	4.3	3.6	3.0	2.0	1.3
	SE ±	0.4	0.7	0.5	0.9	0.4	0.8
August	Free	7.5	12.9	6.4	5.9	1.1	7.0
	Slight, some eyes	6.7	11.5	4.3	5.6	2.4	5.9
	Moderate-severe, all eyes	4.0	11.7	3.1	2.8	0.9	8.9
	SE ±	0.4	0.9	0.4	0.4	0.4	1.0
September	Free	7.8	23.9	6.7	7.4	1.1	16.5
	Slight, some eyes	6.0	16.2	4.6	5.4	1.4	10.8
	Moderate-severe, all eyes	5.5	15.7	3.5	3.8	2.0	11.9
	SE ±	0.6	2.3	0.5	1.2	0.6	1.7
October	Free	7.5	18.8	5.3	6.9	2.2	11.9
	Slight, some eyes	5.4	16.1	4.0	4.5	1.4	11.6
	Moderate-severe, all eyes	5.4	25.9	3.8	4.0	1.6	21.9
	SE ±	0.5	1.9	0.4	0.4	0.6	1.9
AVERAGE	Free	7.7	15.9	6.1	6.5	1.6	9.4
	Slight, some eyes	6.1	12.8	4.3	5.1	1.8	7.7
	Moderate-severe, all eyes	5.1	14.4	3.5	3.4	1.6	11.0

(c) Bush sandy clay-loam soil.

Date of lifting	Level of seed infection	Total stems above ground		Main stems		Lateral stems	
		1968	1969	1968	1969	1968	1969
July	Free	6.2	6.9	4.5	5.4	1.7	1.5
	Slight, some eyes	4.7	6.2	3.3	4.9	1.4	1.3
	Moderate-severe, all eyes	3.6	3.8	1.7	3.4	1.9	0.4
	SE ±	0.7	0.3	0.5	0.5	0.6	0.6
August	Free	6.3	11.3	4.7	6.0	1.6	5.3
	Slight, some eyes	6.4	9.0	3.8	4.9	2.6	4.1
	Moderate-severe, all eyes	4.6	10.0	2.1	1.0	2.5	9.0
	SE ±	0.7	1.8	0.7	0.8	0.7	0.8
September	Free	6.8	11.4	5.5	7.3	1.3	4.1
	Slight, some eyes	6.3	9.3	4.6	5.4	1.7	3.9
	Moderate-severe, all eyes	4.3	14.2	2.2	2.7	2.1	11.5
	SE ±	0.8	1.9	0.4	0.9	0.7	1.8
October	Free	5.5	8.4	4.5	6.6	1.0	1.8
	Slight, some eyes	5.3	9.2	3.8	5.1	1.5	4.1
	Moderate-severe, all eyes	5.2	9.3	2.5	4.4	2.7	4.9
	SE ±	0.7	1.7	0.5	0.8	0.5	1.5
AVERAGE	Free	6.2	9.5	4.8	6.3	1.4	3.2
	Slight, some eyes	5.7	8.5	3.9	5.1	1.8	3.4
	Moderate-severe, all eyes	4.4	9.4	2.1	2.9	2.3	6.5

Appendix II Tuber number per plant in relation to level of seed infection and time of harvest, 1968 and 1969.

(a) Loamy sand soil.

Date of lifting	Level of seed infection	Ware		Seed		Chats		Total	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	-	-	15.6	4.5	22.1	37.9	37.7	42.4
	Slight, some eyes	-	-	9.9	2.1	15.8	28.4	25.7	30.5
	Moderate-severe, all eyes	-	-	3.3	0.0	10.8	0.0	14.1	0.0
	SE ±	-	-	1.3	0.9	2.6	6.2	3.6	6.3
August	Free	4.8	5.6	14.4	13.6	12.2	24.6	31.4	43.8
	Slight, some eyes	4.5	5.0	13.4	10.9	8.8	23.3	26.7	39.2
	Moderate-severe, all eyes	6.1	2.3	9.8	10.4	8.4	8.8	24.3	21.5
	SE ±	1.5	0.9	1.5	2.4	2.1	3.1	3.0	4.3
September	Free	6.6	6.1	12.3	9.5	14.5	16.8	33.4	32.4
	Slight, some eyes	2.2	7.4	13.8	9.5	7.3	13.5	23.3	30.4
	Moderate-severe, all eyes	5.7	8.5	9.4	2.0	6.7	5.0	21.8	15.5
	SE ±	0.9	1.2	1.6	1.9	1.9	2.0	3.2	3.2
October	Free	6.5	9.0	13.0	9.0	8.3	16.6	27.8	34.6
	Slight, some eyes	4.3	8.1	10.5	9.1	3.4	11.1	18.2	28.3
	Moderate-severe, all eyes	6.6	9.8	7.8	3.3	2.6	4.9	17.0	18.0
	SE ±	1.3	2.0	1.5	1.8	1.2	2.1	2.7	3.4

(b) Boghall sandy clay-loam soil.

Date of lifting	Level of seed infection	Ware		Seed		Chats		Total	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	-	-	-	-	12.3	10.4	12.3	10.4
	Slight, some eyes	-	-	-	-	3.0	4.1	3.0	4.1
	Moderate-severe, all eyes	-	-	-	-	0.0	0.0	0.0	0.0
	SE ±	-	-	-	-	1.8	1.4	1.8	1.4
August	Free	0.4	0.9	10.5	10.4	11.8	5.9	22.7	17.2
	Slight, some eyes	0.6	1.6	9.4	9.8	9.0	4.6	19.0	16.0
	Moderate-severe, all eyes	0.5	0.0	5.3	2.1	7.6	10.3	13.4	12.4
	SE ±	0.3	0.4	0.9	1.5	1.5	1.6	2.0	2.3
September	Free	2.4	10.0	12.6	4.5	8.7	6.4	23.7	20.9
	Slight, some eyes	3.4	7.9	8.8	5.1	6.4	4.9	18.6	17.9
	Moderate-severe, all eyes	2.1	5.8	8.8	4.6	4.8	2.4	15.7	12.8
	SE ±	0.9	1.3	1.4	0.7	1.1	0.9	1.8	1.7
October	Free	5.3	10.4	7.9	6.1	4.6	4.6	17.8	21.1
	Slight, some eyes	4.2	7.5	9.5	4.0	2.1	2.0	15.8	13.5
	Moderate-severe, all eyes	6.7	10.3	5.3	5.0	2.3	1.8	14.3	17.1
	SE ±	0.8	1.6	0.9	0.8	0.5	1.0	0.7	2.4

(c) Bush sandy clay-loam soil.

Date of lifting	Level of seed infection	Ware		Seed		Chats		Total	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	-	-	-	-	-	2.1	-	2.1
	Slight, some eyes	-	-	-	-	-	0.3	-	0.3
	Moderate-severe, all eyes	-	-	-	-	-	0.0	-	0.0
	SE ±	-	-	-	-	-	0.2	-	0.2
August	Free	0.1	1.3	9.2	12.0	18.4	7.3	27.7	20.6
	Slight, some eyes	0.5	1.1	8.6	10.0	10.6	10.4	19.7	21.5
	Moderate-severe, all eyes	0.4	0.0	1.3	0.0	8.5	10.0	10.2	10.0
	SE ±	0.2	0.4	2.0	1.9	2.7	1.5	3.5	2.8
September	Free	5.4	5.9	11.8	9.4	10.7	8.1	27.9	23.4
	Slight, some eyes	4.9	5.3	10.5	7.6	10.8	4.9	26.2	17.8
	Moderate-severe, all eyes	3.3	4.9	3.9	3.9	3.9	12.0	11.1	20.8
	SE ±	0.9	1.1	1.0	1.8	1.7	2.4	2.7	3.8
October	Free	4.5	7.6	9.7	10.1	4.7	5.0	18.9	22.7
	Slight, some eyes	5.2	7.0	7.1	7.6	3.0	1.5	15.3	16.1
	Moderate-severe, all eyes	3.8	7.9	2.8	3.4	1.6	4.3	8.2	15.6
	SE ±	0.9	1.6	1.2	1.0	0.9	1.2	2.6	2.1

Appendix III Tuber weight (g.) per plant in relation to level of seed infection and time of harvest, 1968 and 1969.

(a) Loamy sand soil.

Date of lifting	Level of seed infection	Ware		Seed		Chats		Total	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	-	-	320	77	85	94	405	171
	Slight, some eyes	-	-	224	34	62	60	286	94
	Moderate-severe, all eyes	-	-	71	0	45	0	116	0
	SE ±	-	-	23	11	14	11	31	20
August	Free	309	391	471	363	34	43	814	797
	Slight, some eyes	281	326	352	318	31	40	664	684
	Moderate-severe, all eyes	156	179	247	269	28	20	431	468
	SE ±	45	74	48	77	6	6	85	99
September	Free	522	445	400	369	37	60	959	874
	Slight, some eyes	170	581	490	380	28	62	688	1023
	Moderate-severe, all eyes	468	507	289	45	28	14	785	566
	SE ±	71	62	51	72	6	8	77	94
October	Free	442	896	363	323	28	60	833	1279
	Slight, some eyes	264	893	303	493	14	57	581	1443
	Moderate-severe, all eyes	485	1171	224	139	11	43	720	1353
	SE ±	91	235	48	139	6	14	102	238

(b) Boghall sandy clay-loam soil.

Date of lifting	Level of seed infection	Ware		Seed		Chats		Total	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	-	-	-	-	28	6	28	6
	Slight, some eyes	-	-	-	-	17	3	17	3
	Moderate-severe, all eyes	-	-	-	-	0	0	0	0
	SE ±	-	-	-	-	6	0	6	0
August	Free	26	45	284	326	60	14	369	385
	Slight, some eyes	37	96	249	275	37	9	323	380
	Moderate-severe, all eyes	23	0	111	37	31	23	165	60
	SE ±	14	26	23	43	9	6	26	48
September	Free	190	1134	422	193	34	31	646	1358
	Slight, some eyes	275	876	303	221	37	17	615	1114
	Moderate-severe, all eyes	190	760	281	213	23	14	494	987
	SE ±	82	179	45	54	6	3	65	210
October	Free	442	1412	252	221	20	14	714	1647
	Slight, some eyes	360	1273	301	167	20	9	681	1449
	Moderate-severe, all eyes	584	1778	167	204	17	9	768	1991
	SE ±	65	249	17	23	3	6	57	258

(c) Bush sandy clay-loam soil.

Date of lifting	Level of seed infection	Ware		Seed		Chats		Total	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	-	-	-	-	-	-	-	-
	Slight, some eyes	-	-	-	-	-	-	-	-
	Moderate-severe, all eyes	-	-	-	-	-	-	-	-
	SE ±	-	-	-	-	-	-	-	-
August	Free	6	85	221	357	79	17	306	459
	Slight, some eyes	28	65	207	238	43	23	278	326
	Moderate-severe, all eyes	20	0	26	0	31	3	77	3
	SE ±	9	12	51	19	11	6	54	63
September	Free	405	573	371	445	40	37	816	1055
	Slight, some eyes	437	502	312	335	37	43	786	880
	Moderate-severe, all eyes	312	593	147	252	17	60	476	905
	SE ±	71	130	34	102	9	11	82	159
October	Free	386	692	312	428	31	28	729	1148
	Slight, some eyes	488	717	252	292	23	9	763	1018
	Moderate-severe, all eyes	357	714	96	119	11	17	464	850
	SE ±	91	173	48	34	6	9	116	176

Appendix IV Percentage surface browning of stems and stolons in relation to level of seed infection and time of harvest, 1968 and 1969.

(a) Loamy sand soil.

Date of lifting	Level of seed infection	Stem		Upper stolon		Middle stolon		Lower stolon	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	30.0	8.8	17.5	11.3	15.0	6.9	27.5	6.9
	Slight, some eyes	37.5	34.4	13.4	9.4	17.7	15.6	28.4	10.6
	Moderate-severe, all eyes	30.0	25.7	10.0	3.8	8.8	7.1	15.0	12.5
	SE ±	5.9	4.7	2.7	4.6	2.7	2.1	3.8	2.6
August	Free	30.0	10.6	24.0	10.6	19.5	6.9	24.5	8.8
	Slight, some eyes	51.5	26.3	44.0	6.9	38.5	13.8	54.0	28.8
	Moderate-severe, all eyes	60.0	37.5	29.4	8.8	50.0	26.9	73.5	35.0
	SE ±	7.1	6.8	9.6	2.6	7.2	7.9	5.6	9.5
September	Free	30.0	13.1	22.0	21.9	16.5	8.9	26.1	8.9
	Slight, some eyes	38.5	38.1	28.5	50.0	29.1	41.3	50.0	44.4
	Moderate-severe, all eyes	59.0	40.0	23.0	5.0	35.5	32.5	31.5	77.5
	SE ±	8.5	7.4	10.9	8.6	8.7	11.0	12.1	9.2
October	Free	92.0	35.6	51.7	15.6	83.3	26.9	72.5	26.9
	Slight, some eyes	93.5	84.4	70.0	36.3	65.0	73.8	90.6	75.0
	Moderate-severe, all eyes	93.5	78.1	70.5	33.9	70.6	58.1	91.5	86.3
	SE ±	1.6	5.5	10.1	7.5	8.3	15.0	9.6	15.9

(b) Boghall sandy clay-loam soil.

Date of lifting	Level of seed infection	Stem		Upper stolon		Middle stolon		Lower stolon	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	20.0	8.8	15.0	5.0	12.5	5.0	15.0	5.0
	Slight, some eyes	30.0	8.8	35.1	5.0	17.5	5.0	20.0	15.6
	Moderate-severe, all eyes	25.0	26.3	15.0	5.0	12.5	5.0	17.5	18.3
	SE ±	4.4	6.4	12.7	1.6	2.1	3.8	3.2	3.6
August	Free	15.5	22.5	16.5	6.9	6.5	6.9	26.5	25.6
	Slight, some eyes	32.0	35.0	8.0	27.5	16.0	26.3	45.5	50.6
	Moderate-severe, all eyes	56.0	48.1	10.0	6.9	18.0	25.0	34.5	40.6
	SE ±	4.4	8.2	2.9	6.5	3.3	7.5	7.2	9.4
September	Free	14.5	16.3	18.0	15.6	15.5	14.4	24.5	8.8
	Slight, some eyes	27.5	23.8	13.0	20.6	31.0	26.9	39.0	48.8
	Moderate-severe, all eyes	47.5	57.5	25.5	52.5	22.5	73.1	59.0	61.9
	SE ±	8.5	7.3	7.2	12.0	6.4	8.3	10.0	10.8
October	Free	61.5	51.9	55.0	38.8	48.0	52.5	49.3	61.9
	Slight, some eyes	92.0	85.6	72.5	63.8	88.8	71.3	86.5	80.0
	Moderate-severe, all eyes	80.0	90.6	53.5	86.3	52.0	74.4	77.5	84.4
	SE ±	4.7	6.9	9.5	10.0	12.5	12.1	8.3	6.7

(c) Bush sandy clay-loam soil.

Date of lifting	Level of seed infection	Stem		Upper stolon		Middle stolon		Lower stolon	
		1968	1969	1968	1969	1968	1969	1968	1969
July	Free	20.0	5.0	16.3	5.0	12.5	5.0	12.5	5.0
	Slight, some eyes	32.5	6.9	7.5	5.0	17.5	5.0	22.5	5.0
	Moderate-severe, all eyes	42.5	30.0	17.5	5.0	17.5	5.0	27.5	5.0
	SE ±	6.4	7.9	4.2	2.0	3.7	1.7	5.2	2.4
August	Free	8.0	6.9	5.0	13.8	6.5	11.3	11.0	11.3
	Slight, some eyes	46.0	17.5	15.0	16.3	16.0	11.3	48.0	15.0
	Moderate-severe, all eyes	66.0	40.0	11.0	60.0	27.0	5.0	45.5	20.0
	SE ±	4.4	8.0	2.2	7.2	5.8	3.0	8.6	4.8
September	Free	11.0	6.9	8.0	13.8	11.0	8.8	15.5	18.1
	Slight, some eyes	54.0	36.9	12.5	11.3	19.5	6.9	25.0	33.8
	Moderate-severe, all eyes	67.0	64.4	30.5	32.5	33.5	44.5	49.5	40.7
	SE ±	5.1	8.0	4.1	8.5	4.6	8.7	5.6	9.5
October	Free	46.0	32.5	20.5	26.3	12.5	28.1	29.5	22.5
	Slight, some eyes	82.0	70.6	46.7	62.5	75.0	58.8	68.5	87.5
	Moderate-severe, all eyes	74.5	86.3	60.0	31.9	68.8	53.1	73.4	72.8
	SE ±	8.4	7.3	11.6	12.9	9.7	15.2	10.2	11.9

Appendix V Percentage surface area of underground stems and stolons infected with *O. pustulans*, at different dates of lifting, for seed tubers "free" of visible skin spot infection, planted in three soils.

1968

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Stem and stolon position	15 July	12 Aug	9 Sept	8 Oct	15 July	12 Aug	9 Sept	8 Oct	15 July	12 Aug	9 Sept	8 Oct
Stem:-												
upper %	0	0	0	0	0	0	0	0	0	0	1	1
mid %	0	0	0	0	0	1	0	0	1	1	1	2
lower %	0	0	0	0	0	1	0	1	1	1	1	9
Upper stolon:-												
distal %	0	0	0	0	0	0	1	0	0	0	0	1
mid %	0	0	0	0	0	0	2	0	1	0	1	0
proximal %	0	0	0	0	1	0	1	0	0	0	1	1
Mid stolon:-												
distal %	0	0	0	0	0	0	2	0	1	2	1	5
mid %	0	0	0	0	1	0	2	2	1	0	0	5
proximal %	0	0	0	0	0	0	1	2	8	0	2	5
Lower stolon:-												
distal %	0	0	0	0	0	0	1	0	0	0	1	3
mid %	0	0	0	0	0	0	3	3	0	0	1	4
proximal %	0	0	0	0	0	0	1	0	0	0	1	8

1969

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Stem and stolon position	15 July	13 Aug	9 Sept	6 Oct	15 July	13 Aug	9 Sept	6 Oct	15 July	13 Aug	9 Sept	6 Oct
Stem:-												
upper %	0	0	0	0	0	0	1	0	0	1	1	1
mid %	0	0	0	0	0	0	1	0	1	0	0	0
lower %	0	0	0	0	1	0	5	4	0	0	0	4
Upper stolon:-												
distal %	0	0	0	0	0	0	0	0	0	0	0	0
mid %	0	0	0	0	0	0	1	0	0	0	1	1
proximal %	0	0	0	0	0	0	6	0	0	0	5	0
Mid stolon:-												
distal %	0	0	0	0	0	0	0	0	0	0	0	0
mid %	0	0	0	0	0	0	3	0	0	0	0	1
proximal %	0	0	0	0	0	0	5	0	0	0	3	4
Lower stolon:-												
distal %	0	0	0	0	0	0	0	1	0	0	0	1
mid %	0	0	0	0	0	0	0	1	0	0	0	0
proximal %	0	0	0	0	1	0	20	1	0	1	0	8

Appendix VI Percentage surface area of underground stems and stolons infected with *O. pustulans*, at different dates of lifting, for seed tubers showing "slight" skin spot infection with some eyes infected, planted in three soils.

1968

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Stem and stolon position	15 July	12 Aug	9 Sept	8 Oct	15 July	12 Aug	9 Sept	8 Oct	15 July	12 Aug	9 Sept	8 Oct
Stem:-												
upper %	1	4	8	3	5	8	8	5	11	4	4	7
mid %	6	8	16	8	9	5	8	9	16	7	5	22
lower %	13	9	16	2	10	9	14	16	24	11	18	14
Upper stolon:-												
distal %	0	0	9	0	4	5	9	4	1	3	4	0
mid %	2	1	10	0	3	2	14	3	11	11	11	0
proximal %	5	0	13	0	0	12	15	5	11	17	10	0
Mid stolon:-												
distal %	0	13	3	1	2	1	8	3	4	2	8	0
mid %	6	20	16	1	3	6	6	9	6	3	8	3
proximal %	11	32	5	3	9	12	16	3	5	14	16	2
Lower stolon:-												
distal %	2	0	14	8	4	10	13	7	5	17	1	14
mid %	3	9	25	2	5	20	23	15	1	19	2	23
proximal %	9	28	33	3	10	31	34	4	5	31	17	30

1969

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Stem and stolon position	15 July	13 Aug	9 Sept	6 Oct	15 July	13 Aug	9 Sept	6 Oct	15 July	13 Aug	9 Sept	6 Oct
Stem:-												
upper %	4	3	12	1	1	0	4	4	0	5	6	11
mid %	9	3	16	8	4	1	13	9	0	4	9	25
lower %	4	5	18	4	3	2	17	8	1	4	11	33
Upper stolon:-												
distal %	1	2	20	7	1	1	11	1	0	12	6	6
mid %	1	1	30	8	1	1	11	0	0	7	6	18
proximal %	7	1	33	17	3	1	17	2	0	10	18	15
Mid stolon:-												
distal %	2	3	11	4	2	0	21	1	0	1	2	19
mid %	6	2	14	26	3	1	19	3	0	6	1	18
proximal %	21	3	13	21	3	3	26	3	0	13	9	31
Lower stolon:-												
distal %	4	2	13	17	2	1	3	1	1	6	4	13
mid %	2	1	16	13	4	1	16	3	0	7	15	18
proximal %	4	3	31	23	16	1	19	7	1	9	24	17

Appendix VII Percentage surface area of underground stems and stolons infected with *O. pustulans*, at different dates of lifting, for seed tubers showing 'moderate-severe' skin spot infection with all eyes infected, planted in three soils.

1968

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Stem and stolon position	15 July	12 Aug	9 Sept	8 Oct	15 July	12 Aug	9 Sept	8 Oct	15 July	12 Aug	9 Sept	8 Oct
Stem:-												
upper %	5	3	9	2	8	11	3	2	25	12	7	7
mid %	13	10	10	6	18	16	6	3	29	14	4	5
lower %	29	15	19	12	24	11	5	2	30	10	7	3
Upper stolon:-												
distal %	1	1	1	3	1	5	3	6	3	3	13	3
mid %	8	0	5	5	5	3	4	13	3	8	13	1
proximal %	13	6	13	1	6	8	6	3	8	10	16	2
Mid stolon:-												
distal %	1	1	4	3	3	6	3	4	1	2	3	25
mid %	1	3	6	1	5	4	7	4	8	10	6	24
proximal %	11	11	19	15	10	20	10	5	16	16	25	29
Lower stolon:-												
distal %	4	4	4	5	5	8	26	12	8	12	8	3
mid %	14	18	10	9	8	17	31	19	16	26	21	14
proximal %	28	26	15	12	25	15	17	19	33	31	24	11

1969

Soil type	Loamy sand				Sandy clay-loam (Boghall)				Sandy clay-loam (Bush)			
Stem and stolon position	15 July	13 Aug	9 Sept	6 Oct	15 July	13 Aug	9 Sept	6 Oct	15 July	13 Aug	9 Sept	6 Oct
Stem:-												
upper %	0	3	8	1	2	1	6	0	25	12	7	7
mid %	0	4	13	1	2	2	5	0	29	14	4	5
lower %	0	3	5	1	4	3	5	0	30	10	7	3
Upper stolon:-												
distal %	1	3	0	0	3	2	24	0	3	3	13	3
mid %	1	3	0	0	3	3	30	0	3	8	13	1
proximal %	0	6	20	1	0	4	46	0	8	10	16	2
Mid stolon:-												
distal %	1	6	3	0	1	1	3	0	1	2	3	25
mid %	0	16	10	1	0	3	19	1	8	10	6	24
proximal %	2	16	13	1	1	3	22	0	16	16	25	29
Lower stolon:-												
distal %	1	2	13	0	8	2	7	0	8	12	8	3
mid %	1	4	23	1	10	1	8	0	16	26	21	14
proximal %	1	11	23	0	22	5	21	1	33	31	24	11

Appendix VIII Percentage surface area of underground stems and stolons infected with O. pustulans, at different dates of lifting, for seed tubers of different infection levels planted in sterilised or unsterilised loamy sand, inoculated or not inoculated with O. pustulans.

(a) "Free-trace", no eye infection.

Stem and stolon position	Sterilised soil				Unsterilised soil			
	Inoculated		Uninoculated		Inoculated		Uninoculated	
	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept
Stem:-								
upper %	0	0	0	0	0	0	0	0
mid %	0	2	0	0	0	0	0	2
lower %	0	0	0	2	5	3	0	10
Upper stolon:-								
distal %	0	0	0	0	0	0	0	0
mid %	0	0	0	0	0	0	0	0
proximal %	0	0	0	0	0	0	0	0
Middle stolon:-								
distal %	0	0	0	0	0	0	0	0
mid %	0	0	0	0	0	0	0	0
proximal %	0	0	0	2	0	17	0	0
Lower stolon:-								
distal %	0	0	0	0	0	0	0	0
mid %	0	0	0	0	0	2	0	8
proximal %	0	0	0	2	0	2	0	25
Index of total colonisation	0	2	0	6	5	24	0	45

(b) "Slight", some eyes infected.

Stem and stolon position	Sterilised soil				Unsterilised soil			
	Inoculated		Uninoculated		Inoculated		Uninoculated	
	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept
Stem:-								
upper %	0	3	0	2	0	0	0	2
mid %	0	3	0	0	3	0	0	5
lower %	2	3	2	3	0	0	3	5
Upper stolon:-								
distal %	0	0	3	0	0	3	0	0
mid %	1	0	3	0	0	3	0	0
proximal %	2	0	0	5	0	8	0	2
Middle stolon:-								
distal %	0	1	0	0	0	0	0	0
mid %	0	3	0	0	0	0	0	0
proximal %	0	41	0	0	0	2	0	10
Lower stolon:-								
distal %	0	3	5	0	0	0	0	43
mid %	0	3	0	15	0	2	15	43
proximal %	0	50	0	25	0	3	33	43
Index of total colonisation	5	109	13	50	3	21	51	153

Appendix IX Percentage surface area of underground stems and stolons infected with *O. pustulans*, at different dates of lifting, for seed tubers of different infection levels planted in sterilised or unsterilised sandy clay-loam (Boghall), inoculated or not inoculated with *O. pustulans*.

(a) "Free-trace", no eye infection.

Stem and stolon position	Sterilised soil				Unsterilised soil			
	Inoculated		Uninoculated		Inoculated		Uninoculated	
	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept
Stem:-								
upper %	0	2	0	3	0	0	0	0
mid %	0	7	0	13	0	2	0	0
lower %	0	10	2	13	0	3	2	0
Upper stolon:-								
distal %	0	3	0	3	0	0	0	0
mid %	0	2	0	8	0	0	0	2
proximal %	0	13	0	38	0	0	0	0
Middle stolon:-								
distal %	5	0	0	3	0	0	0	0
mid %	15	3	0	3	0	0	0	0
proximal %	18	2	0	3	0	2	0	2
Lower stolon:-								
distal %	0	0	0	0	0	0	0	0
mid %	0	3	0	13	0	0	0	0
proximal %	0	5	3	30	0	3	0	2
Index of total colonisation	38	50	5	130	0	10	2	6

(b) "Slight", some eye infection.

Stem and stolon position	Sterilised soil				Unsterilised soil			
	Inoculated		Uninoculated		Inoculated		Uninoculated	
	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept
Stem:-								
upper %	2	0	2	3	2	0	0	0
mid %	2	0	3	8	3	0	2	0
lower %	2	0	5	3	5	0	3	0
Upper stolon:-								
distal %	2	0	0	0	0	0	0	0
mid %	3	0	2	0	2	0	3	0
proximal %	7	5	5	5	2	0	2	3
Middle stolon:-								
distal %	0	0	2	3	5	0	3	3
mid %	3	0	8	2	5	0	2	3
proximal %	3	0	12	12	5	0	2	8
Lower stolon:-								
distal %	2	2	13	0	2	0	0	5
mid %	8	2	20	3	2	0	0	5
proximal %	13	2	28	15	8	8	2	5
Index of total colonisation	47	11	100	54	41	8	19	32

Appendix X Percentage surface area of underground stems and stolons infected with O. pustulans, at different dates of lifting, for seed tubers of different infection levels planted in sterilised or unsterilised sandy clay-loam (Bush), inoculated or not inoculated with O. pustulans.

(a) "Free-trace", no eye infection.

Stem and stolon position	Sterilised soil				Unsterilised soil			
	Inoculated		Uninoculated		Inoculated		Uninoculated	
	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept
Stem:-								
upper %	0	0	0	0	0	0	0	2
mid %	0	0	0	0	0	0	0	2
lower %	2	2	2	0	3	0	2	3
Upper stolon:-								
distal %	0	0	0	0	0	0	0	0
mid %	0	0	0	0	2	0	0	0
proximal %	0	0	0	0	2	2	0	8
Middle stolon:-								
distal %	2	0	0	0	0	2	0	0
mid %	7	0	0	3	0	2	0	0
proximal %	8	5	0	3	0	2	0	0
Lower stolon:-								
distal %	13	0	8	0	3	0	0	0
mid %	15	0	8	0	0	0	0	0
proximal %	30	0	13	3	3	2	0	10
Index of total colonisation	77	7	31	9	13	10	2	25

(b) "Slight", some eyes infected.

Stem and stolon position	Sterilised soil				Unsterilised soil			
	Inoculated		Uninoculated		Inoculated		Uninoculated	
	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept	19 Aug	10 Sept
Stem:-								
upper %	2	3	0	0	0	7	0	0
mid %	8	12	3	0	2	8	5	2
lower %	8	12	5	0	2	3	3	0
Upper stolon:-								
distal %	30	10	0	0	0	0	0	0
mid %	20	10	0	0	2	8	0	0
proximal %	23	10	0	0	2	3	0	0
Middle stolon:-								
distal %	0	35	0	0	0	0	3	0
mid %	2	45	3	0	7	3	3	0
proximal %	8	75	3	0	3	3	3	0
Lower stolon:-								
distal %	0	22	5	0	0	30	5	3
mid %	10	22	5	0	2	27	5	3
proximal %	2	28	10	0	5	32	10	3
Index of total colonisation	113	284	34	0	25	124	37	11

Appendix XI Skin spot infection in relation to various watering treatments applied during 21 August to 2 October, 1970.

Series A				Series B			
Water withheld until:-	Total water applied (in.)	S.I.I.	E.I.I.	Water applied until:-	Total water applied (in.)	S.I.I.	E.I.I.
21 Aug	7	16.7	23.3	*	0	4.8	12.9
28 Aug	6	8.2	14.0	21 Aug	1	2.3	12.5
4 Sept	5	13.2	16.1	28 Aug	2	3.1	12.5
11 Sept	4	2.6	7.7	4 Sept	3	7.8	17.7
18 Sept	3	4.3	14.1	11 Sept	4	7.8	17.2
25 Sept	2	8.8	21.6	18 Sept	5	5.9	18.6
2 Oct	1	0.5	2.3	25 Sept	6	7.6	20.0
*	0	1.7	0.0	2 Oct	7	3.6	6.3

* No water applied during 21 August to 2 October.

Appendix XII Mean skin spot surface and eye infection in relation to total water applied during 21 August to 2 October, 1970.

	Total water applied (in.)							
	0	1	2	3	4	5	6	7
S.I.I.	3.3	1.4	6.0	6.0	5.2	9.6	7.9	10.2
E.I.I.	6.5	7.4	17.1	15.9	12.5	17.4	17.0	14.8

Appendix XIII Skin spot surface and eye infection indices in relation to different box storage treatments following clamp storage from lifting in October, 1967-69.

Time from lifting (weeks)	S.I.I.				E.I.I.			
	Boxed only		Boxed and disinfected		Boxed only		Boxed and disinfected	
	4°C	10°C	4°C	10°C	4°C	10°C	4°C	10°C
1967								
0	11.3	-	1.3	-	73.0	-	31.0	-
4	10.7	-	6.8	-	82.0	-	64.0	-
6	16.3	-	5.8	-	76.0	-	57.0	-
15	36.1	-	8.7	-	73.0	-	77.0	-
19	21.2	-	14.4	-	86.0	-	71.0	-
23	29.0	-	26.0	-	75.0	-	76.0	-
25	21.3	-	-	-	72.0	-	-	-
1968								
0	7.4	6.1	1.0	1.3	65.3	59.8	16.4	26.9
1	7.7	6.2	5.8	4.1	66.3	70.0	55.5	48.6
3	7.8	6.5	5.0	1.8	72.1	60.6	47.9	30.3
6	8.0	6.9	5.8	4.6	67.8	63.1	50.6	50.9
9	8.3	6.5	7.3	7.1	69.3	65.5	65.4	73.8
12	8.3	6.6	7.0	6.5	72.9	81.9	61.4	64.1
15	8.2	9.1	7.9	6.7	66.5	71.5	67.0	75.9
18	9.1	13.5	8.0	8.7	73.9	75.9	66.6	67.9
1969								
0	7.3	7.0	1.6	1.9	73.2	73.1	38.1	43.5
1	7.7	7.6	4.5	4.7	83.2	76.9	55.7	56.3
3	8.1	7.8	5.2	5.6	84.3	82.1	59.1	68.1
6	8.6	9.1	6.1	7.3	82.0	82.4	63.7	75.6
9	8.9	7.9	8.7	8.8	92.4	79.9	88.6	85.3
12	9.0	8.6	8.9	8.4	95.2	84.8	84.3	88.2
15	9.9	8.3	9.8	8.5	91.4	80.5	87.1	81.4
18	13.4	16.0	10.5	9.9	93.3	85.4	88.6	86.3