Potato Research 30 (1987) 613 – 623

Observations on the incidence of tuber growth cracking in relation to weather patterns

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Accepted for publication: 21 April 1987

Zusammenfassung, Résumé p. 621

Additional keywords: yield, dry matter concentration

Summary

The natural incidence of growth cracking in tubers of the cultivars Guardian and Record in relation to weather conditions and patterns of tuber growth in 1983 – 1985 was investigated by harvesting tubers three times per week throughout each growing season.

The incidence of cracking in tubers of Record was greatest in 1983 and 1984, and was associated with re-wetting of soil after prolonged dry periods. In Guardian, the incidence of cracking in tubers was greatest in 1985 and was associated with wet soil conditions and rapid tuber growth.

Two forms of growth cracking can occur: the one associated with rewetting of soil after tuber growth has stopped, the other with rapid tuber growth and high turgor.

This report reconciles the findings of two earlier reports on growth cracking and the underlying causes of the disorder are discussed.

Introduction

The occurrence of tuber growth cracking is associated with particular cultivars, but the reasons for the phenomenon are not clearly understood. It has been suggested that cracking occurs in response to fluctuating water-stress (Iritani, 1981; van Loon, 1981) and that it is the result of rapid changes in tuber growth rate (Gray & Hughes, 1978). Robins & Domingo (1956) found that its incidence was greatest when there was water-stress in mid-season. However, MacKerron & Jefferies (1985) reported that the relief of water-stress did not reliably induce the disorder in susceptible cultivars and that differences in the incidence of growth cracking in crops which were grown similarly could not be related directly to differences in the rates of tuber growth.

The experiments reported here were designed to observe throughout the season the incidence of growth cracking in two susceptible cultivars, and to relate the incidence to particular weather patterns. If fluctuating water supply caused cracking, then the size of the soil moisture deficit and the degree of re-wetting required to induce the disorder might be determined.

Materials and methods

Field experiments were conducted on the potato cultivars Record and Guardian, grown on sandy loam soils at the Scottish Crop Research Institute in 1983 – 1985. Record is

known to be susceptible to cracking, and Guardian, which was submitted as seedling 8906 AC11 for inclusion in 1979 UK National List Trials, had previously shown some cracking and was withdrawn from the trial by its breeders on the completion of the first year as it had cracked severely at one site.

Each year, prior to planting, fertiliser was applied (175 kg N, 76 kg P and 207 kg K per ha) and oxamyl at 5.5 kg a.i. per ha (Vydate, du Pont de Nemours & Co.) was incorporated as a precautionary measure against nematodes. Seed tubers were planted in April each year in ridges 75 cm apart and at densities of 3.81×10^4 plants per ha in 1983 and 4×10^4 plants per ha in 1984 and 1985. Weeds were controlled by a pre-emergence application of terbutryne with terbuthylazine at 0.8 + 0.35 kg a.i. per ha (Opogard 500L, Ciba Geigy Agrochemicals).

Each year the experiment comprised two blocks planted to both cultivars. The cultivar plots were sub-divided into 27 plots, each containing 9 plants and surrounded by guard plants. Harvests were made at least three times a week from the commencement of tuber growth to mid-September. On each occasion, the plants from one plot of each cultivar were harvested. Harvests alternated between blocks, while plots within a block were sampled sequentially (the results were monitored lest the incidence of cracking differed between blocks but it did not). At each harvest the numbers of stems and tubers and the numbers of tubers exhibiting growth cracks were counted. The depth of the deepest crack on each cracked tuber was measured with a tyre tread-depth gauge. In 1984 and 1985, total tuber yield per plant and tuber dry matter concentration were measured once a week. Dry matter concentration was determined by weighing a sub-sample of the weighed tubers from each plant, dicing the sub-sample and drying it at 90°C for 72 h before re-weighing.

Soil moisture under the crops was measured to a depth of 100 cm, throughout the season with a neutron moderation soil moisture meter with four access tubes installed for each cultivar. Weather records were obtained from the meteorological station at the institute.

Results

Weather

The growing season of 1983 was characterised by cool, wet weather from mid-April until the third week of May. There followed a transition to hot, dry weather which lasted through until the end of August (Fig. 1a). The soil moisture deficit which developed during the season (99 mm) was relieved by rain in late August and early September (Fig. 2). In 1984 (Fig. 1b), temperatures during the period May to August were above average. Rainfall was below average and a soil moisture deficit of 123 mm developed by the end of August. Rain in early September relieved that deficit (Fig. 2). Throughout the growing season of 1985, temperatures were close to or below average, while rainfall was above average (Fig. 1c). A maximum soil moisture deficit of only 20 mm was recorded in mid-July (Fig 2). After that time rainfall kept the soil at close to field capacity.

Incidence of growth cracking

In 1983 and 1984, the incidence of growth cracking in Guardian was very low, less than 1% of the tubers harvested (Fig. 3a, c), and was not associated with any particular weather patterns. The occurrence of cracking was greater in Record in these years (Fig.

Fig. 1. Records of soil temperature at 10 cm depth measured at 09.00 each day and daily rainfall. —— Soil temperature at 10 cm; --- long-term averages (1953 – 1982) of soil temperature at 10 cm; ? daily rainfall. a: 1983, b: 1984, c: 1985.

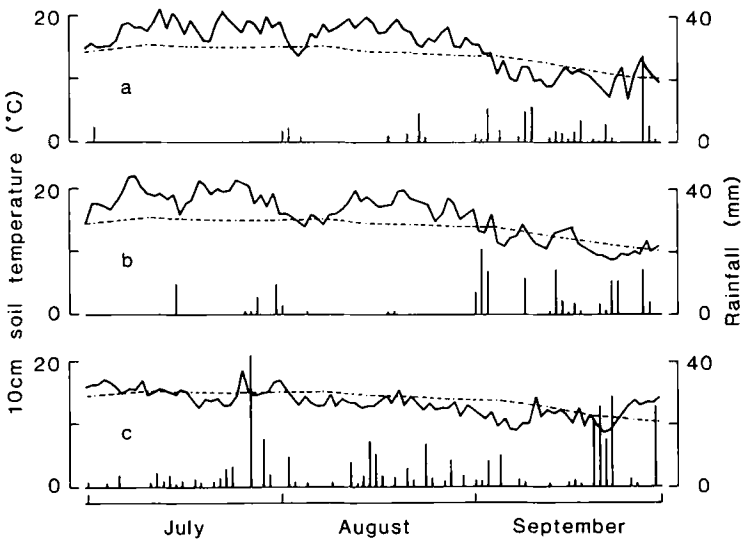

Abb. 1. Aufzeichnungen der Bodentemperatur in 10 cm Tiefe, gemessen täglich um 9.00 Uhr und die täglichen Regenfälle. —— Bodentemperatur in 10 cm; --- langjähriges Mittel (1953 – 1982) der Bodentemperatur in 10 cm; ? tägliche Regenfälle. a: 1983, b: 1984, c: 1985.
Fig. 1. Enregistrement de la température du sol à 10 cm de profondeur mesurée à 09.00 chaque jour et de la pluviométrie journalière. —— température du sol à 10 cm; --- moyenne sur plusieurs années (1953– 1982) de la température du sol à 10 cm; ? pluviométrie journalière. a: 1983, b: 1984, c: 1985.

3b, d) and was associated with the re-wetting of dry soils. The greatest incidence of cracking in Record in 1983 was 0.4 tubers per plant (4% of the tubers harvested), and in 1984 the greatest incidence was 2.2 tubers per plant (12% of the tubers harvested). In 1984 most of the cracking occurred with the relief of severe water-stress by rain in late August to early September. The depths of cracks in tubers of Record were rarely more than 5 mm deep but they were extensive. The surface of the wounds suberized and shallow cracks filled progressively so that the incidence of growth cracking apparently diminished in time.

In 1985, the incidence of growth cracking in Record was low and was not related to any particular weather pattern (Fig. 3f) but in Guardian cracking occurred (Fig. 3e). The maximum incidence recorded in Guardian was 2.1 tubers per plant (14% of the tubers harvested). Cracking first occurred in Guardian in late July after the re-wetting of a 20-mm soil moisture deficit. Growth cracks were much deeper in Guardian than in Record and persisted. From mid-August onwards the occurrence of cracked tubers was almost constant (1.3 cracked tubers per plant, 8.5% of tubers harvested).

The forms of the growth cracks in the two cultivars differed. In Guardian they always took the form of one or more large cleavages several millimetres deep which might almost girdle the tuber and which generally widened to 10 mm or more across at

Fig. 2. Time course of measured soil moisture deficit (mm) in experimental plots. a: 1983, b: 1984, c: 1985.

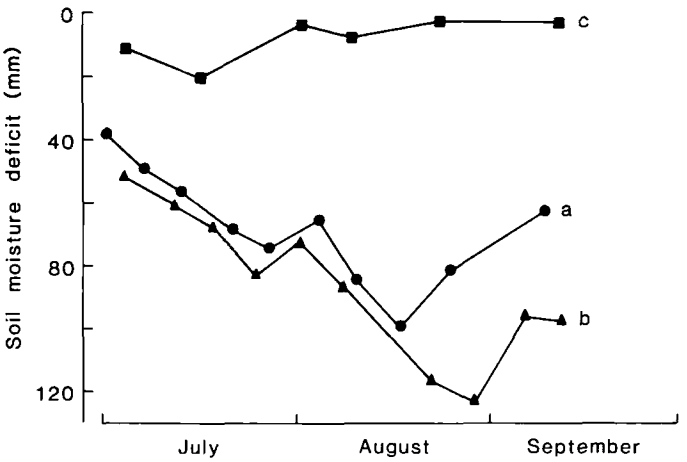

Abb. 2. Zeitlicher Verlauf des gemessenen Bodenfeuchtigkeitsdefizits (mm) in den Versuchsparzellen. a: 1983, b: 1984, c: 1985.
Fig. 2. Déficit hydrique du sol (en mm) déterminé au cours du temps dans des parcelles expérimentales. a: 1983, b: 1984, c: 1985.

the surface of the tuber (Fig. 4a). Such cracks can occur in tubers of Record but more usually the surface of the tubers develops a netted pattern in its epidermis, and then in its periderm, that then extends downwards through the cortex as a crack lengthens and deepens.

The form of growth cracking typical of Guardian produces cracks that are 15 – 25 mm deep (Fig. 3) and have straight smooth edges; the form exhibited by Record (Fig 4b) produces cracks that may become very deep but are usually 2 – 5 mm deep (Fig. 3). The latter have jagged and sharp edges and they progress erratically across the surface of the tuber and do not usually extend for more than one third of the perimeter of the tuber.

Tuber yield

Tuber yield was recorded as an indicator of changes in average tuber size. In 1984 tuber growth in both cultivars had virtually ceased by the end of August, but the relief of water-stress in early September resulted in a rapid increase in tuber yield (Fig. 5), mostly as a result of an increase in the water content of the tubers rather than the accumulation of dry matter. In the period from the end of August until the final harvest tuber water content increased by 34% and 39% in Guardian and Record respectively, while the tuber dry matter increased by only 22% and 11% resulting in reductions in tuber dry matter concentration (Fig. 5) During the period mid-July to mid-August the average rates of increase in yield were 59.7 g m^{-2} day^{-1} in Guardian and 58.6 g m^{-2} day^{-1} in Record.

The rates of tuber growth in 1985 did not exhibit the rapid changes of the previous

Fig. 3. Incidence and severity of growth cracking. Numbers of tubers cracked per m^2 through each season and depth of the deepest crack (mm) at each occasion. ..... running 5-measurement average of incidence of growth cracks. a, c, e – Guardian; b, d, f – Record; a, b – 1983; c, d – 1984; e, f – 1985.

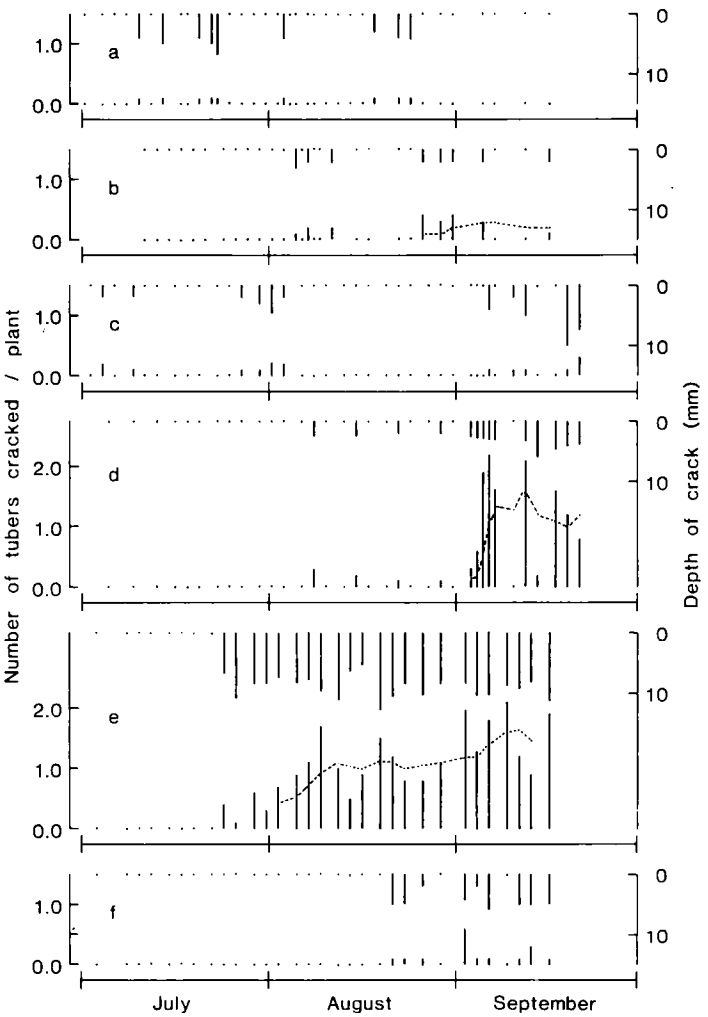

Abb. 3. Umfang und Schwere der Wachstumsrisse. Anzahl der gerissenen Knollen pro m^2 während jeder Saison und die Tiefe des jeweils tiefsten Risses (mm) ..... 5-tägiger Durchschnitt vom Auftreten der Wachstumsrisse. a, c, e – Guardian; b, d, f – Record; a, b – 1983; c, d – 1984; e, f – 1985.

Fig. 3. Incidence et sévérité des craquelures de croissance. Nombre de tubercules craquelés par m^2 et profondeur de la plus profonde craquelure. a, c, e – Guardian; b, d, f – Record; a, b – 1983; c, d – 1984; e, f – 1985.

Fig. 4. The two forms of growth cracking characterised by (a, left) cv. Guardian and (b, right) cv. Record.

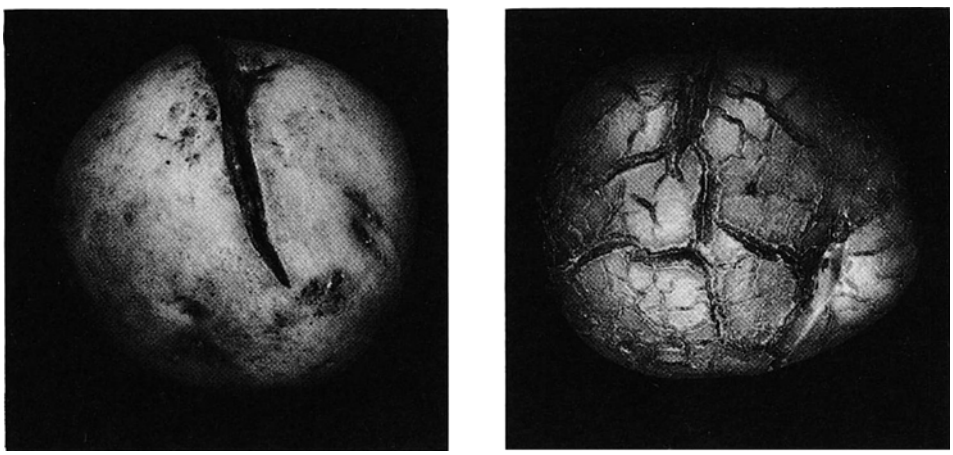

Abb. 4. Die zwei unterschiedlichen Formen der Wachstumsrisse, charakteristisch für die Sorten (a, links) Guardian und (b, rechts) Record.
Fig. 4. Les deux formes distinctes de craquelures de croissance caractérisées par le cultivar Guardian (a, à gauche) et le cultivar Record (b, à droite).

year (Fig. 5), and during the period mid-July to mid-August the average rates of increase in yield were 111 g m^{-2} day^{-1} in Guardian and 109 g m^{-2} day^{-1} in Record.

Discussion

The weather conditions that induced cracking differed between cultivars. Growth cracking occurred in Record when there was relief of soil moisture deficits >70 mm, and the amount of cracking was greater when re-wetting was greater and occurred from greater deficits. In contrast, tubers of Guardian did not crack when severe soil moisture deficits were relieved, but did crack when a deficit of only 20 mm was relieved, and the soil moisture content remained close to field capacity. Growth cracks occur as a secondary symptom in tubers produced by plants raised from seed tubers infected with potato mop top virus (PMTV) (Calvert, 1968). However, none of the plants exhibited any of the foliar symptoms or the primary tuber symptoms of PMTV infection and growth cracking can occur in plants of these cultivars that are known to be healthy. The different forms of growth crack exhibited by the two cultivars corresponds with the different conditions that induce cracks. The large cleavages that characterise cracking in Guardian occurred in only one of the three seasons studied and then they occurred in two stages; the main stage immediately followed a period of very rapid growth when yield increased at 147 g m^{-2} day^{-1} or by 54% in one week. There was a second smaller increase in incidence following a late spurt in tuber growth (Fig. 3 and 5). These observations suggest that, in Guardian, very rapid growth of tubers may cause stresses in the tissues perhaps due to an imbalance in the growth of the medulla, the cortex and the periderm. These stresses lead to mechanical failure in the periderm and cortex and the rapid formation of a tear across the tuber.

In Record, growth cracking was a serious problem in 1984 only, and then it too occurred after a cessation of tuber growth as indicated by the running 5 – measurement mean of number of cracked tubers. Tubers had almost stopped growing by 31 August when rain over three days re-wetted the soil surface. The incidence of growth cracks increased sharply over the following six days but it was not until ten days later that there was a measurable increase in yield. It is, therefore, not clear whether the growth cracking observed in Record occurred on the recommencement of tuber growth or on its cessation as happened in 1985 when there was a slight occurrence at the very end of the growing season when yield had stopped increasing.

Most previous reports on the problem of growth cracking in potato tubers have been anecdotal (Gray & Hughes, 1978; Iritani, 1981; van Loon, 1981) and none have distinguished between the two forms of cracking that we have recognised here (Fig. 4). The evidence of Robins & Domingo (1956) suggested that growth cracking was associated with mid-season water-stress followed by a resumption of water supply but MacKerron & Jefferies (1985) showed that such a sequence of soil moisture conditions did not reliably induce the disorder. This report reconciles these findings. Conditions which produce very rapid growth of tubers, which may or may not accompany the relief of water stress, can produce the large cleavage cracks observed in the cv. Guardian (Fig. 4a) if these growth rates are high enough. The relief of water-stress also can induce the jagged tearing cracks observed in the cv. Record (Fig. 4b) where the preceding stress has been sufficient, along with other conditions, to cause cessation of tuber growth. The first form of growth crack can also occur in Record.

Two problems remain; the first is how to account for the development of growth cracks in Record when tuber growth has ceased, and the second, which may be related, is how to account for varietal differences in susceptibility to growth cracking.

Fracture cracking of potato tubers, a form of mechanical damage at harvest, has generally been considered to be a separate phenomenon from growth cracking. However, Schoorl & Holt (1983) concluded from compression studies on potato tubers that cracking occurred when the potential energy within a tuber exceeded a critical value.

Susceptibility to mechanical damage, including fracture cracking, varies with cultivar and is influenced by environment. Lampe (1960) found that tubers from areas with the highest rainfall were damaged by lowest rupture force. Finney & Findlen (1967) showed that tubers from irrigated plots damaged more easily than those from unirrigated plots, and that high turgor increased their susceptibility to damage. These are the conditions associated with growth cracking in Guardian, but not in Record which is resistant to mechanical damage (Grant & Hughes, 1985). If the static forces within a tuber that is turgid and expanding rapidly can be equated with the quasi-static forces from compression tests then it may be that fracture cracking and growth cracking of the Guardian type are related phenomena.

Growth cracking in Record may be the result of uncoordinated changes in cell sizes in the several tissues of the tuber causing stresses in the cortex and periderm. This would be consistent with the observation that growth cracks in Record are, initially at least, shallow and extensive.

Clearly there are two distinct forms of growth cracking, one associated with high turgor and rapid tuber growth, the other with the rapid uptake of water when dry soils are re-wetted. Progress in the understanding of each form will require studies of the internal stresses in the tissues of tubers, their tensile strength and the elasticity of their cells. In the meantime, any tests of the susceptibility of cultivars to growth cracking should take account of the two forms that we have described.

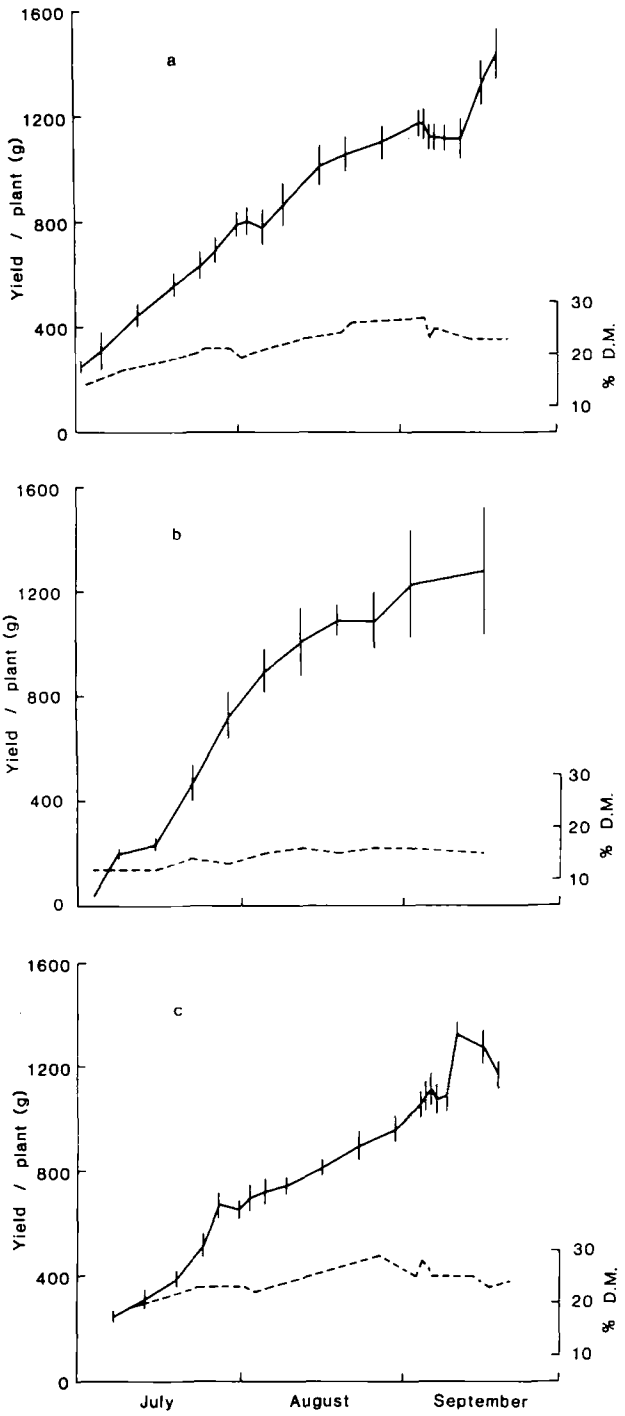
a
b
c
Yield / plant (g)
1600
1200
800
400
0
30
20
10
% D.M.
July
August
September

Fig. 5. Progress of yield of tubers and tuber dry matter concentration in two seasons and two cultivars (a) Guardian, 1984, (b) Guardian, 1985, (c) Record, 1984, (d) Record, 1985. —— yield, --- dry matter concentration.
Bars represent standard errors of the means.

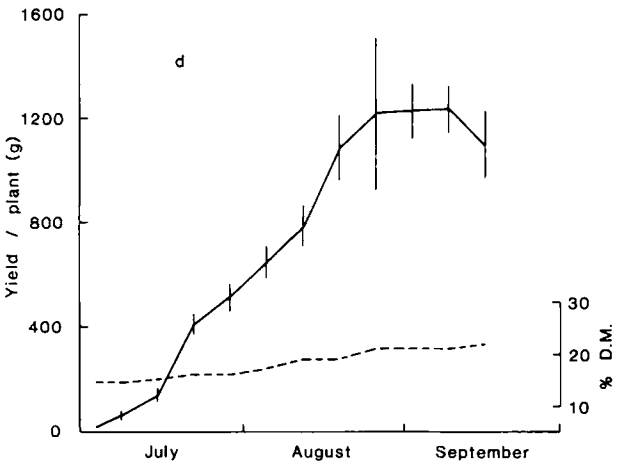

Abb. 5. Verlauf des Knollenertrages und der Knollentrockenmasse in zwei Wachstumsperioden und bei zwei Sorten. (a) Guardian, 1984, (b) Guardian, 1985, (c) Record, 1984, (d) Record, 1985. —— Ertrag, --- Trockenmasse.
Die Längsstriche repräsentieren den Standardfehler der Mittelwerte.
Fig. 5. Evolution du rendement et de la teneur en matière sèche des tubercules pour deux années et deux cultivars. (a) Guardian, 1984, (b) Guardian, 1985, (c) Record, 1984, (d) Record, 1985. —— Rendement, --- Teneur en matière sèche.

Zusammenfassung

Beobachtungen über das Auftreten von Wachstumsrissen an der Knolle in Bezug zur Witterung

In Versuchen, mit denen das natürliche Auftreten von Wachstumsrissen in Bezug zur Witterung untersucht werden sollte, wurden Knollen von zwei anfälligen Sorten, Guardian und Record, während der Zeit des Knollenwachstums dreimal wöchentlich geerntet und der Umfang und die Schwere der Risse gewertet.

In den beiden warmen (Abb. 1) und trockenen (Abb. 2) Jahren 1983 und 1984 war das Auftreten von Wachstumsrissen an den Knollen der Sorte Guardian nur gering (Abb. 3), und es gab keine Beziehung zu irgendwelchen besonderen Witterungsverhältnissen. In den gleichen Jahren waren bei der Sorte Record 4% bzw. 12% der geernteten Knollen rissig (Abb. 3). Die Wachstumsrisse bei Record wurden in Verbindung gebracht mit der Wiederbefeuchtung des Bodens nach längerer Trockenheit. Die Ermittlungen des Knollenertrages (Abb. 5) und der Knollentrockenmasse wiesen darauf hin, dass das Reissen dem Ende des Knollenwachstums folgte und verbunden sein kann mit einem schnellen Anstieg des Wassergehaltes der Knolle.

In der Wachstumsperiode 1985 (Abbildungen 1 und 2) war das Auftreten der Wachstumsrisse bei der Sorte Record gering und nicht an besondere Witterungsverhältnisse

gebunden. Im Gegensatz dazu traten bei Guardian bemerkenswert häufig Risse auf, 14% der geernteten Knollen waren gerissen (Abb. 3). Die Wachstumsrisse bei Guardian standen in Verbindung mit nassen Böden und einer Periode sehr schnellen Knollenwachstums. Die Wachstumsrisse bei Guardian schienen das Ergebnis eines übermässigen hydrostatischen Druckes in schnell wachsenden Knollen zu sein.

Es gab zwei verschiedenen Formen von Wachstumsrissen (Abb. 4), wovon jede typisch war für eine der untersuchten Sorten. Dieser Bericht bestätigt die Ergebnisse früherer Berichte über Wachstumsrisse, und es werden die dieser Schädigung zugrunde liegenden Ursachen diskutiert.

Résumé

Observations sur l'incidence des craquelures de croissance des tubercules en relation avec des modèles climatiques

Dans des expérimentations destinées à observer l'incidence naturelle des craquelures de croissance et à établir un rapport entre celles-ci et les conditions climatiques, des tubercules de deux cultivars sensibles, Guardian et Record ont été prélevés trois fois par semaine pendant toute la période de grossissement des tubercules. L'incidence et la sévérité des craquelures ont été enregistrées.

En 1983 et 1984, en périodes de croissance à la fois chaudes (figure 1) et sèches (figure 2), l'incidence des craquelures sur les tubercules de Guardian était basse (figure 3) et n'était pas en relation avec un modèle climatique particulier sur Record, les mêmes années, respectivement 4% et 12% des tubercules prélevés étaient craquelés (figure 3). Les craquelures de croissance sur Record étaient associées à une réhumectation du sol après des périodes de sécheresse prolongées. Les déterminations de rendement (figure 5) et de teneur en matière sèche des tubercules montraient que les craquelures faisaient suite à l'arrêt de croissance des tubercules et pouvaient être associées à une augmentation rapide de la teneur en eau des tubercules.

En 1985, en période de croissance humide (figure 1 et 2) l'incidence des craquelures de croissance sur Record était basse (figure 3) et n'était pas en relation avec des modèles climatiques particuliers. Par contre, il y avait une occurrence marquée de craquelures sur Guardian: 14% des tubercules prélevés étaient craquelés (figure 3). Les craquelures de croissance sur Guardian étaient associées à des sols humides et à une période de très rapide croissance des tubercules. Elles semblaient être le résultat d'une pression hydrostatique excessive dans les tubercules ayant grossi trop rapidement.

Il y a eu deux formes distinctes de craquelures de croissance (figure 4), typiquement liées à la variété étudiée. Ces travaux complètent les résultats des premiers rapports sur les craquelures de croissance et les causes sous-jacentes de confusion sont discutées.

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