DEPARTMENT OF INDUSTRY AND COMMERCE
METEOROLOGICAL SERVICE

TECHNICAL NOTE No. 12

POTATO BLIGHT AND THE WEATHER
A FRESH APPROACH

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DUBLIN
JANUARY 1953

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SUMMARY

The results of controlled laboratory experiments on the environment favourable to the development of certain plant diseases and pests may, in some cases, be adapted for use with routine meteorological observations, and so make the basis for a warning service to farmers. This is illustrated in the case of Potato Blight. A new set of criteria is developed for the recognition of weather spells favourable to Potato Blight in Ireland. The criteria are intended for application to routine hourly weather reports, the results being interpreted and expanded by reference to the synoptic weather situation. The synoptic approach enables the meteorological situations which are favourable and unfavourable to the blight fungus to be classified, thus permitting a true forecast of the onset and spread of the disease to be attempted.

1. INTRODUCTION

It is well known that weather conditions have a marked influence on the time of onset and subsequent development of attacks by many plant diseases and pests. The usual approach in seeking the relationship between weather factors and different plant diseases has been to look for correlation between meteorological data and the results of plant disease surveys. In many cases, this has enabled certain broad conclusions to be drawn e.g. that Apple Scab in Britain tends to be worse after a wet May, and that Clover Rot is more severe when a mild Winter follows a wet Autumn (Ministry of Agriculture and Fisheries 1947). In the case of potato blight, it has long been recognised that a hot, dry growing season inhibits the spread of blight on the foliage, whereas moist and sunless weather favours its development. Several workers have endeavoured to establish a precise relationship between weather factors and this disease; the criteria which they have suggested are discussed later.

In some cases, interesting attempts have been made, not to relate meteorological factors directly to the disease or pest, but to find natural parameters having a reaction to the weather environment similar to that of the parasites. It has been claimed, for instance, that in Bavaria a close relationship exists between the date on which snowdrops bloom and the intensity of the plague of field mice which occurs in some years in that area.

Butler (1925) suggested that there were limitations to the method of basing weather relationships on plant disease and pest surveys, saying that "the trend of recent work has been to show that definite conclusions cannot safely be drawn from such observations unless they are controlled and elucidated by the more exact methods of laboratory research." He underlined "the importance of beginning at the other end - of first establishing the temperature and humidity relations of the parasite and host, singly and together, and only then, with the exact information thus gained, seeking the correlation with meteorological data."

Butler commented that, at the time of writing (1925), it was doubtful if the meteorological data then recorded were sufficient for the purpose. Since that date, and mainly under the stimulus of aviation requirements, the amount of available weather data has grown considerably; the records of stations making hourly observations are particularly adapted for use in the application of plant disease relationships.

The present paper describes an attempt to base a potato blight forecasting service in Ireland on the published results of controlled laboratory studies of the reaction of the responsible parasite to its environment. As the paper is addressed primarily to meteorologists rather than plant pathologists, the more important features of the disease and of the fungus which causes it are described.

2. EFFECT OF POTATO BLIGHT ON THE CROP

Potato Blight, which is known in some countries as "Late" Blight, is the most important disease attacking the potato in Great Britain and Ireland. It is caused by the fungus Phytophthora infestans (Mont.) de Bary. This parasite, in common with all other fungi, lacks chlorophyll. Being therefore incapable of photosynthesis, it cannot utilise the carbon dioxide of the air directly in the building up of carbonaceous food, but must make use of the organic matter already available in the foliage and tubers of the potato or in the other solanaceous hosts such as the tomato which it also attacks.

Potato Blight causes crop losses in two separate ways - by reducing the yield and by causing some of the tubers actually formed to rot either in the ground or in storage.

Yield is reduced beause of the damage done to the foliage of the plants. In Ireland, experiments carried out over a number of years have indicated an average loss in yield of up to 20% (Department of Agriculture 1951). In tests carried out under relatively severe conditions of potato blight incidence in Devon and Cornwall during the years 1941-4, Large (1945) found that protective spraying resulted in a mean prolongation of foliage growth of 16½ days and a mean gain in total yield of 2¾ tons per acre.

The tubers may become infected when spores of the disease are washed down by rain from the haulms into the soil. A further and important source of tuber blight occurs when the crop is dug out at a time when the disease on the foliage is producing spores, or soon afterwards, so that the tubers become infected through coming into contact with the aerial spores or with contaminated surface soil.

The protective spraying measures taken against potato blight are only effective when the disease is at a vulnerable stage. The class of downy mildews (Peronosporales), to which such diseases as Potato Blight and Onion Mildew belong, differ from the true or powdery mildews which attack apples, roses, grass and corn, and which are caused by fungi which live on the surface of leaves and stems and merely send suckers into the superficial cells of the plants in order to feed. In Potato Blight, on the other hand, the vegetative part of the fungus, which is called mycelium, spreads within the leaves and other organs of the host plant, and emerges through the surface only for the purpose of sporulation and only in suitable environmental conditions. It is at the sporulation stage that the disease is vulnerable and the purpose of applying fungicides is to destroy or prevent the germination of the spores when they alight on healthy tissue and so to prevent the spread of the disease.

The time of onset of potato blight and its subsequent course varies considerably from year to year and in different districts. The primary advantage of a reliable service of potato blight weather warnings would be to indicate optimum times for spraying. Protective measures which are followed by a period of complete inactivity of the fungus are merely a waste of material and labour, for not only is the fungicidal layer gradually washed away from the foliage but fresh growth can give rise to a substantial area of completely unprotected leaf surface (Large et al, 1946). On the other hand, undue delay in spraying may have much heavier economic consequences. A further possible use of blight weather warnings, where the haulms are not destroyed or removed well in advance, is in discouraging the lifting of the potato crop at a time when active spores are present.

3. EARLIER CRITERIA FOR THE IDENTIFICATION OF WEATHER FAVOURABLE FOR POTATO BLIGHT

Van Everdingen (1926, 1935), on the basis of a study of weather conditions immediately preceding outbreaks of potato blight in the Netherlands in the years 1919-1923, laid down the following conditions, which may conveniently be referred to as the Dutch rules:-

(1) Dew occurring for at least four hours during the night.

(2) Minimum night temperature not less than 50°F.

(3) Mean cloudiness of the day following the dew at least 0.8

(4) Rainfall of the day following the dew at least 0.1 mm.

If any day occurred on which all these conditions were obeyed, blight usually made its appearance on the foliage within a fortnight.

The Dutch rules were used to set up a spray-warning service in the Netherlands in 1927.

Arising out of tests of the Dutch rules in South Devon, Beaumont (1947) decided, on the basis of eleven years blight data for Southwest England, that more direct account should be taken of relative humidity and proposed the following conditions, which will be referred to as the English rules:-

(1) Minimum temperature not less than 50°F, and
(2) Relative humidity not below 75%
} for at least two days

Using stations which make hourly reports, a critical period under the English rules may be considered to have occurred if, in a sequence of 48 hourly observations, the screen temperature does not fall below 50°F nor the relative humidity below 75%.

The English rules have the merit of greater simplicity. They have been tested in slightly modified form in the Netherlands (Post and Richel 1951) and found satisfactory. They have also been tried in France (Limasset 1939) over a single season, and, as happened on occasions in England, although they were generally satisfactory, they were not successful in forecasting the start of slight local epidemics.

Both the Dutch and English rules are in large measure empirical, being originally derived from field observations of blight outbreaks as related to the preceding weather, although the rules themselves can be shown to have general phytopathological significance by comparing them with the results of laboratory studies on the biology of the blight fungus. The reverse approach which has been attempted in Ireland requires some knowledge of the life-history of the fungus and of its reaction to varying environment.

4. THE LIFE-CYCLE OF THE POTATO BLIGHT FUNGUS

Today, after over one hundred years of ravages by potato blight in Western Europe, there are still a number of incompletely answered questions regarding the responsible fungus, Phytophthora infestans. One of these is the problem of how the fungus first reaches the foliage each year (Murphy & McKay 1927). It is generally agreed that primary outbreaks of blight in the field usually arise from the planting of tubers which, although they show little visible signs of the disease, have in fact carried the infection within them from the previous year. When such infected tubers are planted, many die in the ground without the emergence of aerial shoots; in such cases the fungus spreads into the immediately surrounding ground and may be transferred to the foliage of other plants either in earthing-up work or through the agency of soil-inhabiting insects. Some infected seed potatoes give rise to healthy, if not particularly vigorous, plants; and some few send diseased shoots above the surface, which, before they die, act as primary foci for the start of the disease. Discarded tubers in or on the ground, or remaining in old potato pits, may also contribute starting points for the disease. A complete analysis of the fluctuation of potato blight from year to year is impossible without some knowledge of the variation in the number of primary foci in the fields; this variation may bear some relation to the incidence of blight in the seed growing areas in the previous year. For the present purpose, it is sufficient to note that, given favourable environmental conditions, the development of blight in an area seems rarely, if ever, to be inhibited because of the absence of the pathogen.

Given the required humid conditions, the mycelium within the infected foliage pushes out short extensions through the leaf surface into the air, forming the characteristic white mould which is to be seen on such occasions, normally on the under surface of the leaves. Primary spores or sporangia form on these aerial extensions; they are extremely small and light, and are readily detached and dispersed by air currents. The sporangia are not long-lived, and unless they encounter conditions suitable for their further development within a few hours, the chances of their survival are slight. The sporangia are capable of directly infecting the host, but the optimum temperatures for this direct germination are much higher than those prevalent in our climate. Of far greater practical importance is the process of indirect germination whereby each sporangium, in suitable conditions, can give rise to a number of secondary spores or swarmspores. The swarmspore itself germinates by putting out an extension or germ tube with which it penetrates the host and so establishes a secondary infection of the disease.

An interval elapses between the time of inoculation and the first visible appearance of infection on the plant. The length of this period of incubation depends on the temperature, being shortest at 20° to 23°C. In our climate, it may be taken to be approximately four days.

Neither the initial infections on the primary foci, nor frequently, the first slight extensions of the attack are normally sufficiently obvious to lead to visual detection of the disease, which often has made some progress before it comes to notice.

5. EFFECT OF ENVIRONMENT ON THE POTATO BLIGHT FUNGUS

The relationship which exists between environmental factors and the development of *Phytophthora infestans* has been carefully examined in controlled laboratory experiments by a number of workers. Crosier (1934) summarises the rather complex results as follows:

"It can be seen that the epiphytotic appearance of late blight depends primarily on certain weather conditions. In fact it is very evident that the failure of late blight to occur at any and all times during the growing season is attributable directly to the lack of these certain weather factors.

"The host plants are susceptible at any stage of their development, and the fungus is present almost invariably in a given area; therefore an epiphytotic will occur whenever the correct weather conditions prevail. A temperature of 18° to 25°C. and a relative humidity of nearly 100 per cent over a period of at least 6 hours, or a temperature of 12° to 15°C. and a relative humidity of 100 per cent over a period of 12 or more hours, is necessary for the formation of sporangia. These spores lose their viability in 1 to 2 hours in a very dry air (20 to 40 per cent relative humidity), or in 3 to 6 hours in air of 50 to 80 per cent relative humidity, so that the proper conditions for indirect germination of the sporangia must prevail within a short time after formation.

"These conditions, as Melhus (1915), Everdingen (1926), and Reddick (1928) have explained, are the presence of moisture and a low temperature (from 10° to 15°C) for a period of ½ hour to 2 hours. Indirect germination also takes place at temperatures as low as 3° and as high as 21°C., but the time required is considerably longer and the percentage of germination is much less than at the optimum of 13°C. During this period of germination a large number of swarmspores are liberated, which then germinate and establish their germ-tubes in the host tissues if moisture persists for a few hours. This process requires at least 2 to 2½ hours at 10° to 25°C.

"After the penetration tubes have become established in the host tissues, the fungus develops most rapidly at a temperature of 18° to 21°C. Continuous temperatures above 30° check the growth of the fungus, and therefore (lengthen) the period of incubation; but intermittent temperatures of 20° at night and 30° during the day are not particularly unfavorable. Lesions will appear in three to five days after the establishment of the fungus in the host tissues, and, if the same conditions of temperature and humidity are repeated, a second and naturally more general infection will be initiated. An epiphytotic occurrence of blight results whenever this process is repeated for a sufficient number of times to allow for the spread of the spores to the greater number of the host plants."

6. MODEL FOR IDENTIFYING POTATO BLIGHT WEATHER

The perfecting of a model for the identification of weather favourable for the development of potato blight involves the compilation of a tentative set of criteria essentially simple but incorporating what appear to be the indispensible conditions as revealed by laboratory experiments, testing these criteria against blight developments in the field, and introducing such modifications as may appear necessary, for subsequent retesting. Even the finally evolved model can scarcely avoid the defects of over-simplification and over-rigidity - over-simplification because the complexity of the phenomena involved cannot be precisely reflected in any easily handled formula; over-rigidity because, if the criteria are to be in a form capable of objective application by a number of workers, they must introduce abrupt, and to a certain extent, arbitrary discontinuities which appear in nature only as gradual transitions. This does not mean that the evolution of a good working model would not be of considerable value, just as the frontal model has proved a most useful practical tool to the forecaster.

The first model prepared for the recognition of blight weather in Ireland is intended for use with standard hourly meteorological reports, and requires, as a minimum -

(a) A 'humid period' of at least 12 hours with the temperature equal to, or greater than 50.0°F and the calculated relative humidity equal to, or greater than 90%. (Conditions favourable for the formation of sporangia)

(b) Free moisture on the leaves for a subsequent period of at least four hours (conditions favourable for the germination of the sporangia and for reinfection). If there is no precipitation, the alternative requirement is a further four hours beyond the initial twelve, with relative humidity at least 90% i.e. conditions such that condensed moisture is likely to remain on the leaves for at least four hours after sporangia have formed.

For assessing the relative importance of humid spells of different lengths, account is taken of the "effective period", which is defined as the total duration less eleven hours in the cases accompanied by precipitation, or less fifteen hours when rainfall is absent. Consecutive spells separated by five hours or less are coalesced for calculating the "effective period."

In this first model, the emphasis has been placed primarily on relative humidity. To quote Crosier (1934): "Sporangia never formed in an atmosphere of less than 91% relative humidity, and no trace of aerial mycelium appeared below 85 per cent. It can be stated, by way of comparison, that sporangia formed more quickly and abundantly in a saturated atmosphere at 6°C than in an atmosphere of 91 per cent relative humidity at 21°C". A relative humidity of 90% or over at the level of a standard meteorological screen is assumed to correspond to saturation or near saturation in a low plant cover such as potato foliage. In fact, a sequence of screen humidity values above 89% normally includes a preponderance of values above 95%.

The minimum temperature criterion of 50°F which has been tentatively adopted corresponds to that required in the Dutch and English rules. A maximum temperature limit has not been specified as being rarely of practical importance in Ireland; a ceiling of the order of 70°F would need to be stipulated in regions where such temperatures are reached in moist overcast weather. The question of the necessity to make allowance for inhibition of the disease by higher temperatures, particularly in the period following a favourable spell, is being further studied. Waggoner (1950) has found that instrument shelter temperatures can be used without correction as the basis for potato blight forecasts.

Humid spells are frequently accompanied by persistent rain or drizzle, in which cases prolonged wetting of the foliage is assumed without further ado. When the precipitation is sporadic, an element of subjectivity enters in deciding whether free moisture is likely to be present on the leaves at the required time and for the required period. A tentative criterion in border-line cases stipulates that appreciable rainfall should take place not more than five hours before or not more than three hours after the time of sporangia production; the time intervals given are likely however to prove too generous.

It should be mentioned that the primary objective in defining the first model was to specify minimum conditions which must precede first appearances of the disease in any year; it may later be found desirable to set up two separate models, one of minimum conditions to indicate earliest attacks, however slight, and another, more exacting, for forecasting important changes in the intensification of the disease later in the season.

7. THE PROBLEM OF MOISTURE ON THE LEAVES

The presence of moisture on the foliage at the proper time is of such vital importance to the propagation of the disease that it deserves particular attention. Although morning dew is frequently mentioned in the literature as favouring the spread of the potato blight fungus, it appears from the laboratory experiments that it is unlikely by itself to play an important role unless associated with some sixteen hours of near-saturation conditions. Furthermore (Beaumont 1947), dew does not form readily on potato leaves; much less readily, for example, than on grass. Crosier (1934) found that field inoculations with swarmspores made in the morning following heavy depositions of dew resulted in infection on only those few occasions when the foliage remained wet for a period of 3 to 4 hours after the plants had been inoculated.

There is considerable difference of opinion as to the kind of precipitation which effectively wets potato foliage. Aitken (Board of Agriculture 1892) says - "I have repeatedly walked through potato drills after heavy showers and have been surprised to find how little they have been wetted. The nature of the leaf is such as to throw off drops of rain and leave its surface dry. The kind of rain which is able to drench the leaves of the potato plant is a heavy mist somewhat resembling the spray." The Annual Report (1936) of the Department of Plant Pathology, Seale-Haynes gives a different opinion - "As long as the potato foliage is wet infection will occur, and heavy rain will wet the leaves as efficiently as dew. Owing to the hairy surface potato leaves are not readily wetted by light rains." Published work on the wetting of leaves (e.g. Fogg, 1947, Linskens 1950) contains no relevant reference to the particular question of wettability of potato foliage. The problem has additional interest in its possible relevance to the initial resistance of the foliage of particular varieties of potato to penetration by the fungus.

As a first approach to this question, potato plants have been grown this year at several of the Irish meteorological reporting stations and visual observations made each hour of the wetness or otherwise of the leaves.

8. WEATHER OBSERVING STATIONS AND POTATO BLIGHT WARNINGS

The institution of a potato blight warning service requires, not only the adoption of satisfactory criteria for the recognition of favourable weather, but also a decision on the weather observations to be used and the manner in which they are to be used.

In the Netherlands, weather observations are made at eight special stations, erected as far as possible in, or in the immediate neighbourhood of potato fields, and so distributed as to take in all the most important potato growing areas in the country. Thus each station serves as the basis for warnings in a limited zone.

A different procedure has been followed in Ireland. Use has been made of existing hourly reports from ordinary stations of the synoptic network. Initially, the stations participating have been Claremorris, Co. Mayo; Valentia Observatory, Co. Kerry; Midleton, Co. Cork, and Dublin Airport. At least one additional observing post is desirable in South-East Ireland.

The use of a limited network of stations is possible, because no attempt is made to associate definite areas permanently with each station, nor are the individual 'blight weather' reports from the observing points employed directly as the basis of potato blight warnings. Instead, they are used purely as alerting signals. Each case is examined in the light of the causing agency in the current synoptic situation and a map is drawn to show the probable limits of the area affected and the approximate effective duration of favourable weather in different parts of the area. Thus a report of spot 'blight weather' from Valentia Observatory may prove in one case to be due to wet sea-fog affecting the South-West coastline to a depth of only a few miles, and in another may be caused by a broad invasion of tropical air affecting a very much wider area. The application of the method is illustrated in some detail in Technical Note No.13:- "The Potato Blight Weather Warning Service in Ireland in 1952."

Although the synoptic approach of synthesis and generalisation from a limited number of standard weather observations is simple and inexpensive, it is open to legitimate criticism on the grounds that no direct account is taken of the microclimate within the potato crop, which is the environment in which the potato blight fungus develops. However, it is unfortunately true that even an expensive network of special weather observations from every potato field in the country would not fully cover the local variations in susceptibility to blight. Any complete analysis would need to take account of such factors as the resistance of different potato varieties to infection, the existence of different strains of the fungus, the marked differences in microclimate even in a single field (caused by damp hollows, shading by trees and hedges, different rates of foliage growth, etc.), and variations in the amount of initial pathogen present as affected by the cleanness of the seed, the growth of affected groundkeepers, the distance from old potato storage pits, the presence of discarded diseased tubers and similar sources.

Although there are often wide variations in the local effects of the disease, it is possible each year to draw a broad over-all picture of the course of blight over a general area; indeed it is remarkable in how many seasons this main course runs on similar lines in neighbouring countries, e.g. Ireland, England and France. Important though the main local variations may be, it is the general progress of the disease which is of main economic importance; and this appears to be primarily determined by the general weather situation. The situation therefore closely resembles that of ordinary forecasting for an unstable air mass; it is not possible to give the exact time, place and intensity of individual showers, but the districts and period during which showers are likely to occur in a certain area can be indicated.

9. SYNOPTIC WEATHER SITUATIONS AND POTATO BLIGHT

The synoptic approach to the problem of the relationship of weather to potato blight leads naturally to an attempt to classify meteorological situations as favourable or unfavourable to the onset and spread of the disease.

A preliminary analysis has enabled certain broad conclusions to be drawn in respect of Ireland. Any situation favouring prolonged dry and/or sunny weather hinders the spread of potato blight. Hence dry anticyclonic weather will normally completely check the progress of the disease. Sunny periods, even in showery weather, are also unfavourable; thus a check in favourable weather, sometimes lasting for a week or longer, occurs when a depression is followed by a direct break-through of unstable polar air which interrupts the westerly sequence, and which, although giving quite wet showery weather, does not lead to the muggy overcast weather favourable to the spread of the infection. Also inhibiting to blight is the development of "blocking action" in the Atlantic and the consequent breakdown of westerly weather. This applies not only in the ordinary case of blocking by means of a ridge of high pressure in mid-ocean but also includes the case in which a cold low becomes stationary to the West of Ireland, and diverts warm and active depressions to the south of the country.

The following kinds of weather situation favour the development of blight in Ireland:-

(a) Broad warm sectors, particularly with further wave development following.

(b) Depressions and/or fronts, (including thundery lows or troughs) quasi-stationary over the country, and giving lengthy periods of damp cloudy weather.

(c) Westerly sequence of weather, with quick succession of frontal troughs, uninterrupted by direct cold air outbreaks from the Arctic, so that overcast weather is virtually continuous and rainy spells are frequent.

(d) Persistent fog, and in particular inland penetrations of wet sea fog.

10. FORECASTING WEATHER SITUATIONS FAVOURABLE TO BLIGHT

Because of the incubation period of the disease, a warning, based on reliable criteria for recognising blight weather as it occurs, will precede the visible appearance of the resulting infection by at least several days. Once the favourable synoptic situations have been recognised, it is possible to go a step further and attempt to forecast blight weather before it occurs. The normal difficulties of extended forecasting are somewhat minimised in this case for two reasons. Firstly the forecasts are required only in the normally settled Summer season and do not extend to either of the difficult transitional weather periods which often occur in March-April and October-November. Secondly, and more important, the precise timing of humid spells is of little significance for this work; it suffices to know whether such spells, of appreciable length, are likely to occur or not.

In the first season of broadcast blight weather warnings in Ireland, it has been thought prudent to combine the forecast and actual observations i.e. to issue warnings only when a significant humid period had already been observed and to indicate simultaneously whether the following weather was expected to be favourable or not. The warnings also included, when appropriate, a forecast of periods which might prove suitable for spraying work, as regards precipitation and wind.

REFERENCES

Beaumont, A. 1947 Trans. Brit. Mycol. Soc., 31, p.45

Board of Agriculture (London) 1892 Report C.6647, p.40

Butler, E.J. 1925 Inter. Rev. Sci. Prac. Agric. (Rome), N.S., 3, p.369

Crosier, W. 1934 Cornell Univ. Agric. Exp. Stn. Mem. 155

Dept. of Agriculture 1951 Leaflet No.14

Dept. of Plant Pathology, Seale-Haynes 1936 Annual Report, p.22

Fogg, G.E. 1947 Proc. Roy. Soc., B, 134 p.503

Large, E.C. 1945 Ann. Appl. Biol. 32, p.319

Large, E.C., Beer, W.J., and Patterson, J.B.E. 1946 Ann. Appl. Biol. 33, p.54

Limasset, P. 1939 Ann. des Epiphyt., N.S., 5, p.21

Linskens, H.F. 1950 Planta, 38, p.591

Melhus, I.E. 1915 Univ. Wisc. Agric. Exp. Stn. Bull. 37

Ministry of Agriculture and Fisheries (London) 1947 Bull. No.126, p.1

Murphy, P.A. and McKay, R. 1927 Sc. Proc. R. Dublin Soc., N.S., 18, p.413

Post, J.J., and Richel, C. 1951 Landbouwk. Tijdschr., 63 p.77

Reddick, D. 1928 Phytopath., 18, p.483

Van Everdingen, E. 1926 Tijdschr. PlZiekt., 32 p.129

Do. 1935 Tijdschr. PlZiekt., 41 p.125

Waggoner, P.E. 1950 Bull. Amer. Met. Soc., 31, p.326