DISCUSSION AND CONCLUSION

In India, late blight was first recorded in the Milgiri hills in the South (Butler, 1918). Strangely enough the disease did not occur there again until 1961. Its recurrence might have been brought about by infected tubers in some imported seed. Dastur (1917) reported that potatoes were grown continuously in Mahabaleshwar hills (Maharashtra), but no late blight had been observed there. The position even now continues to be the same as no blight has so far been observed in these hills. This is very likely due to the absence of the source of infection. However, blight may appear there as soon as the inoculum is available. Therefore, care has to be taken in not importing any seed from blight affected areas. In the northern hilly tracts of this country blight was first recorded at Darjeeling, wherefrom it spread to other northern hill ranges from East to West (Butler, 1903 and Dastur, 1917). However, it is now the most serious disease in these areas.

In the North Indian plains the occurrence of the blight was sporadic till 1947 (Dastur, 1948 and Lal, 1948). The view of Dastur (1915) and Butler (1918) that the appearance of blight in the plains was connected with the planting of the potato seed imported from the hills, has now been amply proved. In the plains, the
seed is imported from the hills for planting the winter crop. This seed contains a large number of blight affected tubers and on account of winter rains the weather during this period is congenial for the development of blight. Therefore, the blight commonly occurs in the plains during January and February. Besides infection in the seed raised in the hills, infected tubers are also present in the harvest of the late blight affected winter crop. This harvest is kept in the cold store as seed for the next summer crop. The blight organism in the infected tubers remains viable in the cold store (Pushkarnath and Paharia, 1963). That greatly increases the amount of inoculum for primary infection of the subsequent crop. Thus, with annual large-scale importation of potato seed from the hills as well as the use of seed from cold stores, the blight occurrence in the plains is now observed almost annually.

The climatic conditions in India differ widely from region to region and the observations made on the occurrence of late blight have indicated that there are definite periods during which the disease breaks out in different regions. The monsoons break out early in May or June in the eastern parts of the northern hills. The blight, therefore, appears early in these parts. On the other hand, the monsoons reach the western parts late and the blight too occurs late,
sometime during July and August. The appearance of blight seems to coincide with certain particular weather conditions. If meteorological data are recorded carefully during these blight periods, as shown in the thermohygrograms presented here for different regions, it would be possible to forecast the appearance of the disease and adopt timely control measures. Cox and Large (1960) devised climograms to indicate the blight periods. These climograms are based on the rainfall of a place. However, it has been observed that it is the humidity that is important rather than the rainfall (Harrison, 1947 and Bourke, 1955). Late blight was observed to occur in the plains of India even when there was no rainfall (Dutt, 1962). The author, therefore, developed thermohygrograms after climograms of Cox and Large (1960). These are based on the temperature and humidity records and have proved useful in indicating more correctly the blight periods in different regions.

Dry and hot areas are known to be free from blight (table 1). Such conditions prevail in the plains of Peninsular India and the absence of late blight there testifies to this view. However, there is every possibility of the occurrence of late blight under conditions favourable for the development of the disease if blight affected seed produced in the hills is planted. The winter crop raised with this seed
should, therefore, always be carefully examined for late blight appearance and the adoption of timely control measures. The foregoing observations may tempt one to suggest the raising of seed potatoes in blight-free areas and its distribution to other parts. This is hardly possible on account of heavy virus infection as well as prevalence of brown rot (*Pseudomonas solanacearum* E.F.S.) in some of these areas.

Natural infections of late blight have been reported in different crops, garden plants and weeds (Tucker, 1933). In India, it is potato that is mainly affected by the disease. The author has observed slight infection on leaves of *Nicandra physaloides* Gaertn. Butler (1903) observed a heavy blight infection on tomatoes. However, no blight was observed on tomatoes during the last 12 years even when grown beside the severely infected potato crop either in the hills or in the plains. It is possible that a race of the organism then developed and affected the tomato crop.

Unlike many other countries, the different potato growing regions in India are far apart from each other and have varied climatic conditions. Techniques had, therefore, to be standardised for obtaining from these areas blight affected material for the study of different races of *Phytophthora infestans* (Mont.) de Bary. It was observed that infected leaves could be obtained from the northern plains as the weather there is quite cool.
during the crop season. However, from the hills it was only possible to obtain leaf material from places like Mukteswar which are not far off. The leaves obtained from distant places like Ootacamund, rotted enroute on account of high temperatures in the plains. The inoculated tubers, no doubt, could be obtained from all parts of the country. In these studies single lesion isolations were found useful. But for greater coverage of area, tests with composite samples proved most helpful.

Difficulties have been encountered in assigning the correct race designation on account of erratic registration of infection of the detached leaflets of differential hosts (Webb and Bonde, 1956; Howatt, 1957 and Kammermann et al., 1959). Similar difficulties were also experienced by the author. It was observed that leaflets taken from differentials with R genes that were planted in the glass house under warm and humid conditions during summer developed some sporulation even when inoculated with race 0. However, the leaflets of the same genotype plants raised in the field did not get infection of race 0. It was observed that tough detached leaves taken from healthy plants before the flowering stage when grown at 20°C were good enough for race determination tests. However, this aspect needs to be further standardized for obtaining uniform results.
Happily, the situation regarding physiologic races of *P. infestans* in India is not yet as complicated as in most of the other countries. The present studies have shown that only three races (0, 1 and 4) are met with in different parts of this country. This distribution of only simple races should be expected, as the present commercial varieties in the country possess r gene only. Hide *et al.*, (1959) have also observed that simpler races like 0, 1, 2, 3 and 4 predominate among those races observed on *S. tuberosum* varieties, while specialised races occur mainly on species and varieties possessing R genes. The present position of races in the country, however, may not remain so far long, particularly when blight resistant varieties are being introduced. In all probability the introduction of varieties with R genes is likely to give rise to specialised races of the organism. Taking the experience of other countries into consideration it would be desirable to keep the level of specialised races as low as possible. This may be made possible by the cultivation of potato varieties possessing high degree of field resistance in addition to field immunity to one or two common races of the pathogen.

For selection of resistant hybrids, tests were made for assessing the reaction to blight of both the foliage and the tubers. The tests revealed that there
was no correlation between the foliage and tuber resistance, since a variety with resistance in foliage showed susceptibility in tubers. However, it was observed that the varieties with resistant tubers were also resistant in foliage. This is a useful observation as the resistance tests with the tubers could help in selecting the varieties possessing both tuber and foliage resistance. It is the tubers in which the blight organism perenniates and the infection is, thus, carried from year to year. If varieties with foliage and tuber resistance are selected there are chances of reducing the source of inoculum for the next crop and thereby helping in checking the disease.

Tests with tuber-bearing species of *Solanum* showed that a number of them possessed field immunity to the common races, as observed by other workers (Hawkes, 1947; Rudorf *et al.*, 1950; Cardenas, 1956; Ochoa, 1955; Black and Gallegly, 1957 and Toxopeus, 1960). Similarly, the tests made with varieties and hybrids showed that some of them were field immune to race 0 and some others possessed resistance to the disease. Through crosses with resistant parents, seedlings possessing resistance to blight were evolved. Some of these hybrids were found promising both in the hills and plains and are likely to be selected as commercial varieties.

Magnitude of loss in yield due to damage to
foliage and haulms caused by late blight is obvious from the figures of loss in different countries (Cox and Large, 1960 and Smith, 1962). Similar observations were made by the author, who recorded a loss of about 41 per cent in variety Up-to-Date during 1961. During 1962 the blight appeared about a month later and the loss was observed to be about 30 per cent. The loss, however, rose to about 52 per cent in 1963, when the blight appeared early in a severe form. The data on tuberisation in Up-to-Date has been compiled by Pushkarnath et al. (1962) for the Simla hills. They observed that 40 per cent of tuberisation takes place by the middle of July. The blight usually appears on the crop by this time, and the remaining 60 per cent of the yield is still to be contributed. As the tuberisation continues even after the appearance of the blight, the estimated loss of about 40 per cent brought about by the death of the crop within about a month of the outbreak of the disease seems to be fairly correct. However, the loss of 77 per cent in the variety Up-to-Date in Simla hills reported by Vasudeva and Asad (1952) in 1949, when blight appeared in early August, appears to be very high and difficult to substantiate with the data on rate of bulking of the variety.

Besides the loss in yield brought about by damage to vines by blight, the yields are also reduced by the rotting of tubers affected by the disease (table 21).
No data were available on losses due to rot of blight affected tubers in India. The present studies have revealed that the incidence of blight affected tubers depends upon a number of factors. The author has worked out the influence of factors like tuber size, soil type, plot position in the field, the type of fungicide sprayed and the variety of potato. The results revealed that loss in yield due to tuber rot was high in large-sized tubers as compared to smaller ones. Boyd (1960b) has reported the highest proportion of blighted tubers in chats and lowest in the ware fractions. He felt that it was related to the maturity of the tubers. It is felt that the larger surface area exposed to infection and larger quantity of large-sized tubers in the harvest of the crops in the Simla hills, may be related to high incidence of infection of large tubers.

Soil type was observed to be another factor having a bearing on tuber rot. Losses have been reported to be low in crops raised in sandy loam soils (Melhus, 1949). Similar results were obtained in the present investigation and loss was observed to be low in the sandy loam soil as compared to that in the heavy soils. The losses were also observed to be lower in the higher parts and higher in the lower parts of a field. It is probably the drainage that underlies the two factors of soil type and plot position, which are responsible for
affecting the incidence of infected tubers. The results obtained from spraying the crop showed that tuber rot losses were heavy in the unsprayed crop as compared to that in the sprayed crop. These results corroborate the observations made at Maine (Bonde and Schults., 1949) and in the Republic of Ireland and Prince Edward Island, Canada (Cox and Large, 1960). In the present studies it was also observed that loss is low in the crop sprayed with Bordeaux mixture or any other copper fungicide as compared to the one sprayed with dithiocarbamates. Similar observation had been recorded in Prince Edward Island, Canada (Cox and Large, 1960).

The variety of potato is already known to affect the incidence of tuber rot (Cox and Large, 1960). In the present study it was observed in the Simla hills that an early maturing variety, Craig Defiance, showed a loss of 1.5 per cent tubers by weight due to late blight infection, while in Up-to-Date - a medium maturing variety - which develops serious infection of late blight, the loss was 3.5 per cent.

The above results indicate that the loss due to tuber rot caused by \( P. \text{infestans} \) in Simla hills can be immensely reduced by the cultivation of an early maturing variety, producing small-sized seed tubers, proper drainage of soil and the spraying of crop with Bordeaux mixture. The hills are mainly the seed producing areas because of favourable natural conditions for
production of virus-free healthy stocks. The large-sized tubers produced in the hills have to be cut and used as seed in the plains. The cut seed pieces often show heavy rot resulting in gappy stands. It will, thus, be an added advantage to produce small tubers that may be used as seed.

Control of late blight is an important factor for boosting up the yield of the potato crop. The best method for the control of the disease lies in the cultivation of resistant varieties suffering little loss due to blight. But the production of such varieties is a long-range measure. Even the resistant varieties so developed may show some infection and suffer considerable losses during epidemics. Alternative methods of blight control need, therefore, be adopted.

The next best method of blight control is the protection of the potato crop through the application of fungicides. In Simla hills, Vasudeva and Asad (1952) reported that Burgundy mixture provided the best control of the disease. They had, however, not tried Bordeaux mixture in their experiments. In the present investigations, Bordeaux mixture was found to give better results than the Burgundy mixture or any other proprietary product of fungicide. In these hills, rains are frequent and often heavy. Under such conditions the Bordeaux mixture is known to surpass all other fungicides
in so far as its retenivity is concerned (Bazan, 1955 and Cox and Large, 1960). In the present study this property of the fungicide was further improved by the addition of rosin-soda emulsion as a sticker. Thus, an effective control of the blight was obtained by spraying the Bordeaux mixture.

Bordeaux mixture sprayings increase the rate of transpiration resulting in the reduction of yield in the plains of India (Faharia, 1961). In the hill regions, however, the potato crop is not critically affected by transpiration on account of the very wet weather. For similar reasons Bordeaux mixture has not been found to affect the potato yields in Great Britain (Diamond and Horsfall, 1955).

Some workers have achieved better results by varying the formulation of the Bordeaux mixture. Sanders (1933) got best results with the excess of lime in the Bordeaux mixture while Blodgett et al., (1933 and 1935) and Horsfall and Turner (1943) obtained better results with a mixture containing half the quantity of lime. The author found that decreasing of the quantity of lime resulted in lower yield. A mixture with equal quantities of copper sulphate and lime gave better results. The best results were obtained through the use of 2½:2½:50 formulation of Bordeaux mixture to which rosin-soda emulsion was added as a sticker.
As regards the interval of repeating the fungicidal spraying, Choudhuri (1954) observed that a spraying at 7-day intervals gave the best results in West Bengal. Similar results were obtained in the present experiments. However, the advantage of repeating the spraying at 7-day intervals was offset by other considerations. Apart from the cost involved, there were practical difficulties in covering large areas at frequent intervals in the difficult hilly terrains. At the same time, the rise in yield through the application of fungicide at 7-day intervals was not commensurate with the efforts and expenditure involved. It was observed that the repetition of Bordeaux mixture spraying at 10-day intervals was the most economical and provided a satisfactory control of the disease.

Schedules for spraying of fungicides were drawn up for different regions on the basis of the blight period and optimum time of occurrence of the disease (table 46). It will help in undertaking timely spraying for an effective control of late blight.

Since the occurrence of late blight is an annual feature in the Simla hills, it would be useful to adopt a regular schedule for spraying potato crop with a fungicide to control the disease. It is strange enough that at present no large-scale spraying of the potato crop in these areas is undertaken by the growers. Probably some practical difficulties stand
in the way of undertaking fungicidal control measures. They are, among others, small terraced fields, small holdings, availability of water at long distances, heavy and incessant rains and lack of facilities for servicing spraying equipment. However, these difficulties can be overcome if this work is entrusted to Co-operative Societies with necessary resources and technical know-how. If such societies organise the work of fungicidal spraying of the potato crop, the expenditure would be fully rewarding, as has been shown in the statement on economics of spraying (page 131).

On the basis of the results obtained in the present investigations it is recommended that the potato crop in the Simla hills may be sprayed with Bordeaux mixture (2\%:2\%:50) to which rosin-soda emulsion be added as a sticker. It is further recommended that the first spraying may be completed in the last week of June and the subsequent sprayings may be repeated at 10-day intervals. This recommendation was implemented at the Potato Breeding and Seed Certification Station, Kufri during 1963 with very satisfactory results.

In the northern plains, routine spraying of a fungicide may not always be profitable because of the uncertainty of the occurrence of blight and the difference in intensity of the disease from year to
year. In the plains a blight forecasting service is a necessity and the results secured in the present studies will help in developing such a system. It will still be worthwhile to undertake a protective spraying in the fourth week of December; if the late blight appears, the grower can continue the spraying. This would result in increased yields. In the absence of late blight the prophylactic spraying would help him to keep down the incidence of early blight which poses a serious threat during this time of the year.