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Correlation between intercepted radiation and yield of potato crops infested by Phytophthora infestans in central Africa

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Abstract

It became apparent from chemical late blight control data on large numbers of genotypes of the Rwandese late blight screening programme, that yields were linearly related to the amount of intercepted radiation by the crop. Measures which affected the total amount of intercepted radiation such as the use of contact and systematic fungicides, or of different genotypes, did not affect the radiation use efficiency of the canopy. Genotypes that started to tuberize at relatively low values of intercepted radiation partly escaped the effect of late blight infection of the foliage on tuber yields. This characteristic could be useful to identify early late blight-resistant genotypes for central Africa, where farmers grow two crops per year and earliness is required.

Additional keywords: Late blight score, fungicide, radiation use efficiency.

Introduction

Over 110 000 ha of potatoes are grown annually in the Zaire-Nile Divide region in Burundi, Rwanda, Uganda and Zaire. Yields remain low (7 t/ha) due to diseases and low soil fertility. The potato is generally planted in areas above 2000 m above sea level in two seasons per year, associated with two rainy periods. Many diseases of the potato crop have been recorded in central Africa (Turkensteen, 1984), but late blight caused by *Phytophthora infestans* (Mont.) de Bary is regarded as the disease most limiting potato production in the area. Losses due to late blight are direct through a diminution of the foliage and consequently of yields, and indirect because in order to avoid the disease, farmers tend to plant at the end of the rainy season and then crops suffer from drought. Control measures include the use of resistant cultivars (Bicamumpaka and Devaux, 1984), chemical control with fungicides (Devaux, 1984) and shifting planting dates while applying a mulch to retain soil moisture (Devaux et al., 1985).

Since Scott and Wilcockson (1978) related the measurement of intercepted solar radiation to the growth of the potato crop, the number of reports on this relationship is growing rapidly. For each environment, the production of dry matter (tubers + foliage) of potato crops free from diseases, is linearly related to the quantity of intercepted radiation. This was shown by Allen and Scott (1980) for temperate climatic conditions and by Haverkort (1985) for the tropical highland conditions. With linearity between the proportion of dry matter in the tuber and total dry matter produced, the following relationship is valid (Haverkort, 1985):

$$Y = RUE \times IR$$

where Y = tuber yield, RUE = radiation use efficiency and IR = the amount of intercepted solar radiation by the crop canopy.

The objectives of the experiments descibed here were to assess the effectiveness of control measures such as the use of different kinds of fungicides and of resistant genotypes, and to evaluate their influence on the amount of intercepted solar radiation and radiation use efficiency.

Materials and methods

Four experiments (Table 1) were planted at the research station of the Rwandese National Potato Programme (PNAP) in Ruhengeri (1°29′ S, 29°37′ E) at 1850 m above sea level. The mean daily maximum temperature is 24 °C and the mean daily minimum temperature 17 °C with little fluctuation during the year. The average annual rainfall is 1400 mm and the mean daily total incident solar radiation is 16.5 MJ m^{-2}. The mean values of precipitation are given in Table 1. In the rainy season, rainfall exceeded evaporation, but in the dry season evaporation was greater than evaporation. The soil at the station was a typical eutrandept. At planting, 350 kg ha^{-1} of diammonium phosphate (18-46-0) was applied in the planting furrow.

In all experiments planting was in rows, 80 cm apart and with 30 cm between the seed tubers in the rows. The seed tubers were between 30 and 45 mm in diameter and were well sprouted. Experiments 1 and 2 were laid down in randomized complete block designs with four and two replicates respectively and plot sizes of 19.2 and 14.0 m^2, respectively. Experiments 3 and 4 consisted of single row plots of 6 m length without replicates.

Table 1. Characteristics of the experiments.

Experiment	Planting date	Genotypes	Treatments	Mean rainfall (mm day^{-1})	Mean evaporation (mm day^{-1})
1	24 Sept. 1983	2 cultivars 8 clones	No treatment Contact fungicide*	3.42	2.11
2	29 Sept. 1983	Sangema	No treatment Contact fungicide* Systemic fungicide**	3.40	2.11
3	19 April 1984	40 clones	No treatment Systemic fungicide**	1.20	2.96
4	19 Sept. 1984	40 clones	No treatment Systemic fungicide**	3.80	1.97

* mancozeb only, ** mixture of mancozeb and metalaxyl.

Two fungicides were used: 1) the contact fungicide Dithane M-45 (mancozeb), henceforward referred to as the contact fungicide; 2) a mixture of a contact fungicide and a systematic fungicide available as Ridomil-MZ containing 64% manozeb and 8% metalaxyl, henceforward referred to as the systemic fungicide. The fungicides were applied weekly with knap-sack sprayers with doses of 2.5 kg ha^{-1} of the commercial products in approximately 1000 l ha^{-1} water.

Of the ten genotypes used in experiment 1, two were cultivars (Sangema and Montsama) and eight were clones originating from CIP tuber families, from CIP (Centro Internacional de la Papa, the International Potato Center in Lima, Peru) introduced into the PNAP breeding programme four multiplications earlier. the cultivar Sangema, used in the experiments is Rwanda's most widely grown cultivar with a good level of horizontal resistance to late blight. The last two experiments compared large numbers of clones with and without late blight control to investigate the relationship between lateness and late blight resistance. The 40 numbered clones all originated from CIP in Peru, introduced as tuber families and multiplied and selected for late blight resistance in four previous growing seasons. Experiment 4 was a repetition of experiment 3, since the latter was established in the dry season (Table 1) and insufficient late blight occurred to obtain any effect from the control measures. There was only one month between the harvest and planting of the two trials and Rindite was used to break dormancy of the seed tubers obtained from experiment 3. Rindite is a mixture of 7 parts 2-chloro-ethanol, 3 parts 1, 2 dichloro-ethane and 1 part carbon tetrachloride. The tubers were subjected to Rindite at a dose of 0.5 ml per kg in a closed container for 48 hours in ambient temperatures.

Total incident solar radiation was recorded daily with a Gunn-Bellani radiation integrator that was calibrated against a Kipp-thermopile solarimeter at the Nairobi Meteorological Institute in Kenya in early 1983. The proportion of ground covered with green leaves was estimated weekly with the aid of a metal frame split in 144 rectangles viewed directly from above. The dimensions of the frame were a multiple of the planting pattern: 80 cm × 90 cm. Two estimates were made on each experimental plot. A similar method was described by Khurana and McLaren (1982) and a linear relationship between the proportion of ground covered with foliage thus found and the proportion of intercepted radiation was shown by Burstall and Harris (1983).

Results

The use of the systemic fungicide metalaxyl with mancozeb gave better control of late blight than the contact fungicide alone as shown from the observations of ground cover (Fig. 1). At 87 days after planting, ground cover on the plots in which late blight was not controlled was 30%, those treated with the contact fungicide was about 50% and those treated with the mixture containing the systemic fungicide was over 70%. Increased ground cover increased the amount of radiation intercepted and this resulted in higher tuber yields (Fig. 2). The two types of fungicides seemed to affect yields solely through their effects on intercepted radiation and did not change the radiation use efficiency which was 6.44 g tuber fresh matter per MJ in this trial.

Ground cover development of the controlled and uncontrolled plots of experiment 1 (mean values of 10 genotypes) are plotted in Fig. 3. Late blight infection resulted in reduced ground cover from day 35 onward and the crop senesced a month before the

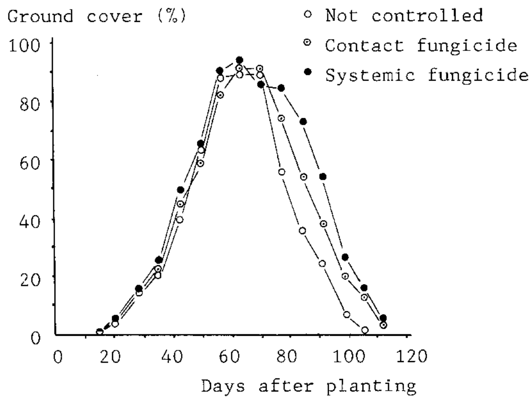

Fig. 1. Development of ground cover of the cultivar Sangema without late blight control and treated with a contact and a systemic fungicide.

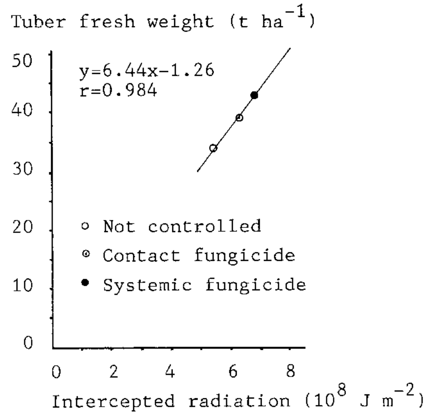

Fig. 2. Relationship between tuber yield and intercepted radiation of the cultivar Sangema without late blight control and treated with a systemic fungicide.

treated crops. The treated plots covered the ground fully for about 40 days before declining naturally. The late blight scores of the controlled and uncontrolled crops are shown in Fig. 4. The slope of the lines which is indicative of the severity of the late blight pressure, differed significantly and was 3.37 times greater in the uncontrolled plots (mean value of 10 genotypes). The varying degrees of ground cover due to different genotypes and late blight control, led to varying amounts of intercepted radiation and yields as represented in Fig. 5. The yield increases in this experiment, as in experiment 2, seemed entirely due to increased intercepted radiation accompanying late blight control and not to increased radiation use efficiencies. Separating the two

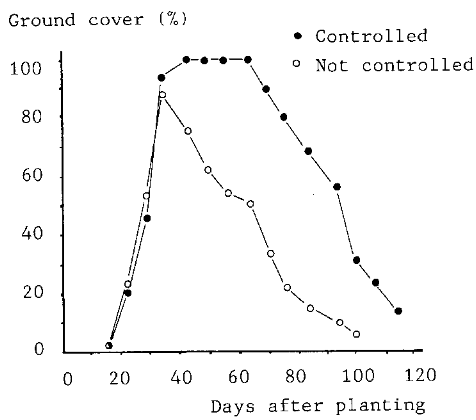

Fig. 3. Mean values of ground cover of 10 genotypes with and without late blight control.

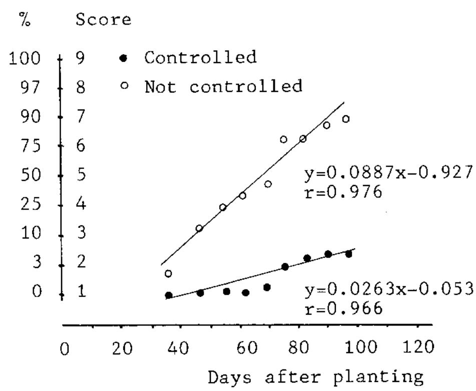

Fig. 4. Late blight infection scores of crops with and without late blight control; mean values of 10 genotypes; the ordinate shows the percentage of leaf destruction due to late blight infection and the corresponding score.

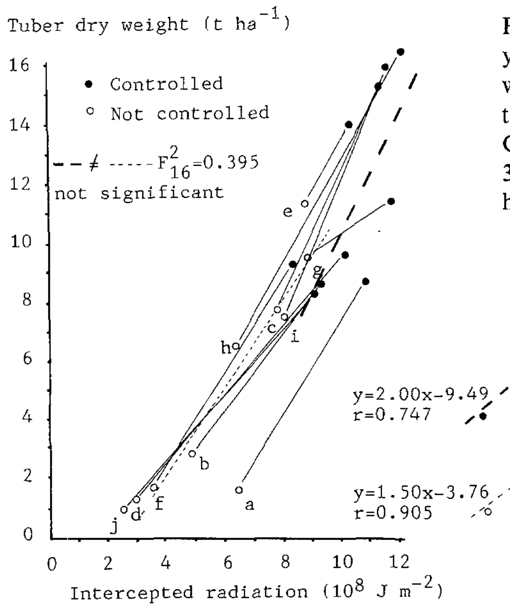

Fig. 5. Relationships between final dry tuber yield and intercepted radiation of 10 genotypes with and without late blight control. The genotypes used were: a: Sangema, b: Montsama, c: CIP 380505-3, d: CIP 380526-10, e: CIP 380082-4, f: CIP 380526-11, g: CIP 380082-2, h: X-220, i: CIP 800935 and j: CIP 380526-6.

regression lines of the treated and untreated plots was statistically not significant (Fig. 5), so both groups belonged to the same regression line with a slope (radiation use efficiency) of 1.53 g tuber dry matter per MJ intercepted radiation. Two genotypes reacted differently from the main group: cultivar Sangema had intercepted a relatively great amount of solar radiation before tuber initiation, possibly because its seed was physiologically young at planting compared with the seed of the other clones; clone

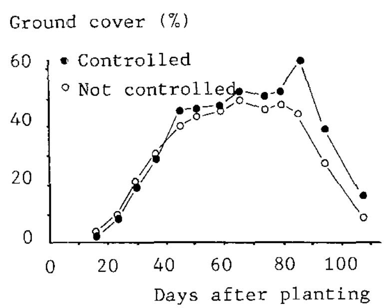

Fig. 6. Development of ground cover; mean values of 40 clones grown in the dry season with and without late blight control.

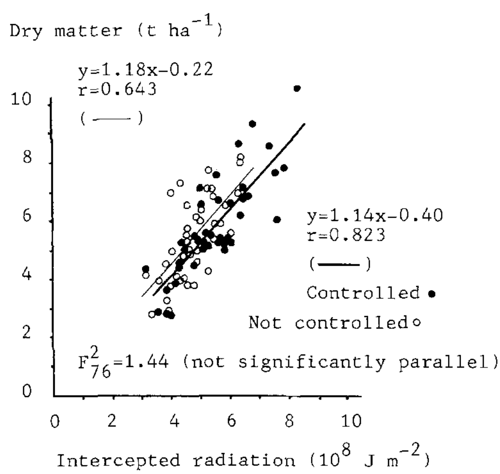

Fig. 7. Relationship between final dry tuber yield and intercepted radiation of 40 clones grown in the dry season with and without late blight control.

CIP 380082-2 with late blight control, suffered from moles damage which seemed to reduce the efficiency of radiation use.

The mean value of ground cover of the 40 clones in experiment 3 did not exceed 60% (Fig. 6) due to the very dry conditions during the growing season. Late blight hardly occured and the differences in ground cover of the treated and untreated plots were minimal. The yields of the treated plots (Fig. 7) were only slightly higher than those from the untreated plots. The two groups of data statistically belonged to the same population; a joint regression line best fitted the data.

A repetition of the same experiment with the same clones in the rainy season of late 1984, showed the influence of late blight control (Fig. 8) on ground cover to be much stronger. The data diverged early in the season, showing that late blight pressure was present from the beginning of the season. The treated crops, on average, remained productive one month longer, and maximum ground cover exceeded 70% whereas it remained below 50% in the untreated crops. The relationship between final tuber yield and intercepted radiation of the 40 clones is shown in Fig. 9. The 40 clones are divided into 4 groups, separated by the regression line and by the line IR = 400 MJ m^{-2}. This line was arbitrarily chosen to divide the clones in groups I and III which intercepted relatively little radiation and groups II and IV that intercepted more radiation. The regression line separated clones (groups III and IV) with a high ratio of tuber yield to intercepted radiation (Y : IR) from clones with low Y : IR values (groups I and II). The mean values of the yields of the groups increased considerably when late blight was controlled (Fig. 10) although the radiation use efficiencies did not change. This suggests that tuber initiation took place at lower values of intercepted radiation and was responsible for the higher ratios Y : IR of groups III and IV.

Periodic harvests took place 49, 64, 90 and 121 days after planting. In the untreated plots, the foliage had virtually disappeared after 90 days and these plots were harvested completely while a part of the treated plots was allowed to grow until complete maturity

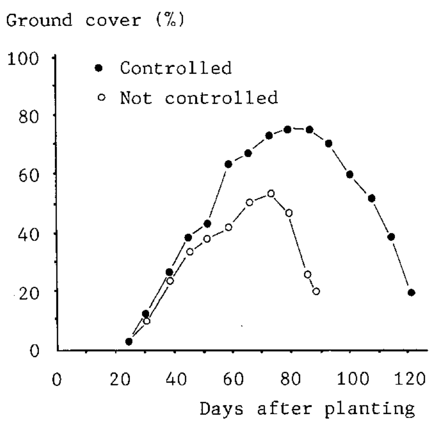

Fig. 8. Development of ground cover; mean values of 40 clones grown in the rainy season with and without late blight control.

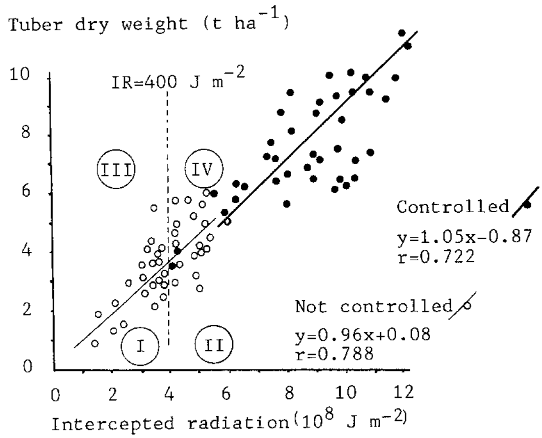

Fig. 9. Relationsips between final tuber dry matter yield and intercepted radiation of 40 clones grown in the rainy season with and without late blight control.

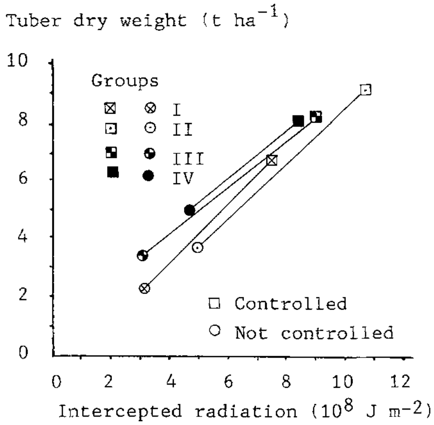

Fig. 10. The relationship between tuber yield at maturity and intercepted radiation of the clones per group, as defined in Fig. 9, with and without late blight control.

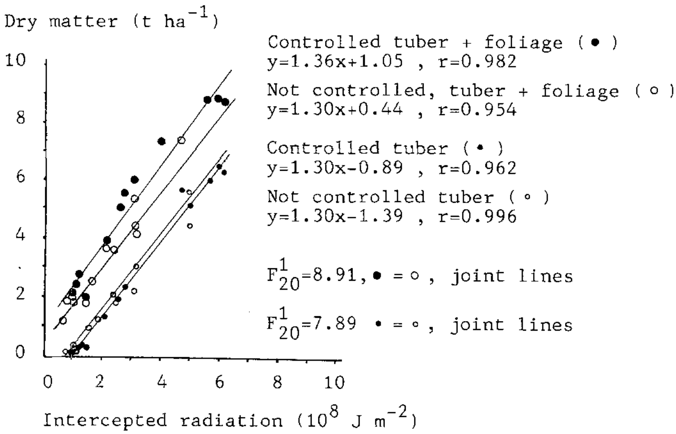

Fig. 11. Relationship between cumulative dry matter production and intercepted radiation of crops with and without late blight control; the groups as defined in Fig. 9 are considered here as replicates.

at 121 days. Comparing the two treatments for the first three harvests (Fig. 11), it seemed that late blight control did not significantly change the radiation use efficiency, either for total dry matter production, or for tuber dry matter production, because statistically significant joint lines for the controlled and uncontrolled crops could be assembled. This was also evident from the r^2 values (derived from the r values) in Fig. 11 which were larger than 0.92 in all cases, indicating that less than 8% variability due to differences in radiation use efficiency occurred.

Discussion and conclusions

Potato yields in this study, were shown to be linearly related to the amount of intercepted solar radiation. The proportion of intercepted radiation of total incident solar radiation was equalled to the proportion of ground covered by green leaves.

Ground cover depended on genotypes and on the severity of late blight attack. The use of fungicides increased ground cover (Figs. 3 and 8) but not radiation use efficiency (Fig. 5, 9 and 10). The fungicide in which metalaxyl was added to mancozeb was more efficient in reducing the effect of late blight on tuber yield and ground cover (Figs. 1 and 2). Planting potatoes in the dry season led to low ground cover values and yields, although late blight and the application of fungicides had little effect under these circumstances (Figs. 6 and 7).

It would seem obvious to suggest that a clone is less susceptible to late blight if late blight control gives lower yield increases. This, however, may not always be valid, because the compatible pathotype of a particular genotype may not have been present at the beginning of the season. Therefore, from the available data of this study, it cannot be concluded with certitude which genotypes were more resistant than others, or which only partly escaped late blight attack. It would be possible to derive relative resistance from the late blight scores plotted against time, but the single row plot screening technique used at PNAP does not give sufficiently reliable data. The epidemiology of the disease in a larger field of only one genotype is likely to be different from the development of late blight in these single row plots, especially if several races and R genotypes are involved.

The study did show one escape mechanism of the plant to late blight which could be useful for the late blight screening technique: early tuberization. When comparing groups III and IV (Figs. 9 and 10) with groups I and II, the former showed apparent tuberization at lower values of intercepted radiation. The combination of early tuberization and early maturity would be especially useful to provide a partial escape from late blight in central Africa. It was often observed in the late blight screening programme at PNAP that late blight resistance is combined with lateness. This is a disadvantage in central Africa where farmers need to grow potatoes in two seasons each year. In practice, they need cultivars which complete the cycle from planting to harvest and from harvest until sprouting in 6 months. Breeding programmes tend to select the most resistant clones, which are late maturing, however. This study has shown that in earlier material, clones exist that escape late blight partly through a pattern of dry matter distribution that leads to early tuber formation and growth.

The finding that late blight does affect the quantity of intercepted radiation but not the radiation use efficiency of the crop, may be important for crop modelling with the aid of linear regression models using fixed conversion coefficients between intercepted radiation and dry matter production. These coefficients are often thought to be valid only in disease and drought free crops (Spiertz et al., 1984), but from the data in this study, it would seem that late blight has no influence on the conversion coefficient.

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Samenvatting

Correlatie tussen opgevangen straling en opbrengst van aardappelgewassen aangetast door Phytophthora infestans in centraal Afrika

De chemische bestrijding van de aardappelziekte in grote aantallen genotypen van het Rwandese veredelingsprogramma voor aardappelziekteresistentie heeft aangetoond dat opbrengsten zich lineair verhouden tot de hoeveelheid door het gewas opgevangen zonnestraling. Maatregelen die van invloed waren op de totale hoeveelheid opgevangen straling, zoals het gebruik van contact- of systemische schimmelbestrijdingsmiddelen, of van verschillende genotypen, waren niet van invloed op het rendement van het gebruik van zonnestraling door het blad. Genotypen die een knolaanleg vertoonden bij verhoudingsgewijze lage waarden van opgevangen straling, ontsnapten gedeeltelijk aan het effect van bladaantasting op knolopbrengst. Dit kenmerk zou van nut kunnen zijn om vroege genotypen te zoeken met resistentie tegen de aardappelziekte in centraal Afrika, waar vroegheid van belang is omdat boeren twee gewassen per jaar telen.

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