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A WEATHER-BASED SCHEME TO ADVISE ON LIMITED CHEMICAL CONTROL OF GROUNDNUT LEAF SPOT DISEASES IN INDIA

By D. R. BUTLER†‡, K. D. R. WADIA†, R. K. REDDY†, N. D. DAS§, B. JOHNSON¶, MEENA KUMARI¶, K. KRISHNA MURTY¶, B. SREENIVAS¶ *and* N. N. SRIVASTAVA§

†*ICRISAT Asia Center, Patancheru, Andhra Pradesh 502324,* §*CRIDA, Santoshnagar, Hyderabad, Andhra Pradesh 500659, and* ¶*DFARS (ANGRAU), Anantapur, Andhra Pradesh 515001, India*

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SUMMARY

Infection of groundnut by pathogens causing early and late leaf spot diseases is strongly affected by accumulated daily leaf wetness periods and, in the rainy season, temperature is unlikely to severely limit infection. Earlier work relating patterns of leaf wetness to infection, was used to define a daily Wetness Index (WI) which was compared with infection on inoculated plants exposed in the crop for periods of 7 d. Infection was only severe when the 7-d WI total exceeded a value of 2.3. The proportion of leaves with one or more lesions on the main stem was used to assess the amount of inoculum in the crop. When the proportion of diseased leaves exceeded 10% and the WI total exceeded the threshold, application of a fungicide was advised. Successive sprays were separated by at least 14 d and a maximum of three sprays were applied in the growing season. Field trials showed that three sprays gave limited benefit where the disease pressure was severe, but substantial increases in pod and haulm yield were possible with only one or two fungicide applications in locations with less disease pressure.

INTRODUCTION

Two widespread foliar diseases of groundnut (*Arachis hypogaea*) are early leaf spot (ELS), caused by *Cercospora arachidicola* and late leaf spot (LLS) caused by *Phaeoisariopsis personata.* These diseases cause premature defoliation and are commonly a major constraint to both seed yield and good quality haulm production. In countries with high-input agricultural systems, the use of fungicides to control these diseases is normal practice, and sprays may be scheduled by fixed-interval timing or by an advisory scheme which depends on weather conditions.

In the USA, advice to control ELS was based for many years on a scheme suggested by Jensen and Boyle (1966) to reduce the number of sprays from those applied at fixed intervals. However, the extent of reduction in disease varies with location and season (Damicone *et al.*, 1994; Wu *et al.*, 1996) and the advisory

‡Address for correspondence: Cocoa Research Unit, The University of the West Indies, St Augustine, Trinidad and Tobago, West Indies.

scheme was commonly not accepted by growers (Smith and Littrell, 1980). The weather variables used in the Jensen and Boyle scheme are daily minimum temperature and periods when the relative humidity (rh) exceeds 95%. Their assumptions, based on field observations, were that the disease would become more severe as the minimum temperature increased and with longer periods of high rh. More recently an alternative scheme was suggested by Cu and Phipps (1993) which also uses temperature and threshold rh but is more comprehensive than the Jensen and Boyle model. They considered conditions conducive to sporulation, germination of conidia, infection and survival of the pathogen separately, and obtained significantly better disease control than the Jensen and Boyle scheme with a similar number of fungicide applications in Virginia (Cu and Phipps, 1993). In Oklahoma, disease control was superior to the Jensen and Boyle scheme (Wu *et al.*, 1996).

Another approach to provide advice for control of LLS uses the number of days when rainfall exceeds a threshold (Davis *et al.*, 1993). This was the basis of the AU-Pnuts advisory scheme (Jacobi *et al.* 1995), established in south-east USA where both early and late leaf spots occur, but LLS predominates. Field trials over a number of years were used to determine the amount of daily rainfall constituting a rain event, and the number of rain events required to recommend a fungicide application (Davis *et al.*, 1993; Jacobi *et al.*, 1995). In operation, the two pathogens have not been distinguished and the scheme was found equally as effective against ELS as LLS (Jacobi *et al.*, 1995). Although good disease control was achieved with the AU-Pnuts advisory scheme in Oklahoma, a greater number of fungicide sprays were applied than with the other schemes (Wu *et al.*, 1996).

A critical environmental variable for infection by *P. personata* or *C. arachidicola* is the accumulated period of leaf wetness (Butler *et al.*, 1994; Alderman and Beute, 1986). Rain events and periods of high rh are both related to leaf wetness and may be used as a substitute because direct wetness measurements are not normally available. This problem has been overcome with the EnviroCaster weather monitoring station (Neogen Corporation East Lansing, Michigan, USA) which offers a predictive system for LLS based on measured wetness periods (Nutter and Culbreath, 1991). However the EnviroCaster is expensive and is therefore not suitable for use in developing countries with low-input agriculture.

Rainfed groundnut is grown in India on a large scale, often in locations where long-term average rainfall totals in the crop growing season are small (about 500 mm) but the year-to-year variation is large. In this situation the main limitation to production is drought in low rainfall years, but leaf spot diseases can become very severe in high rainfall years. In our experience, the majority of farmers in these locations never use fungicide to control foliar diseases, even when the losses through disease can be substantial. Average yields are low and, even though groundnut is a cash crop (used mostly for vegetable oil and animal feed), the resource-poor farmers provide minimal inputs.

In years with above-average rainfall, limited use of fungicides to control leaf spot diseases may be justified, especially if it is possible to optimize the timing of applications. This should be possible with a weather-based advisory scheme, but the scheme would have to be not only inexpensive to establish and operate but also efficient. With this in mind, we have used information from controlled environment experiments on the response of *P. personata* to temperature and leaf wetness periods, together with results from field trials to formulate a weather-based advisory scheme (WBAS).

BACKGROUND INFORMATION

Temperature

Since the optimum temperature for infection by *P. personata* ranges from 15 to 25 °C (Butler *et al.*, 1994), naturally occurring temperatures during the rainy season are not likely to limit the process. This assumption is supported by historical records from the Dryland Farming Agricultural Research Station, of the Acharya N. G. Ranga Agricultural University (ANGRAU), Anantapur, located in the centre of the groundnut growing region of Andhra Pradesh. Over a 15-year period (1980–1994), the mean minimum temperature was 23 °C during the rainy season (July–October), and remained between 20 and 25 °C for 96% of the time. Measurements made at the ICRISAT Asia Center (IAC) in the 1993 and 1994 rainy seasons showed that the temperature of wet leaves in groundnut canopies during the rainy season rarely exceeded 25 °C. Since infection only takes place when the leaf surface is wet (Butler *et al.*, 1995), this also supports the assumption that temperature would rarely limit infection.

Leaf wetness

At temperatures conducive to infection (15 to 25 °C), the number of lesions from a given amount of inoculum depends largely on the total period of leaf wetness. After inoculation, the minimum wetness period for infection to take place is 20 h and, as the wetness period increases, the number of lesions increases to an asymptote, reaching 90% of the asymptote after 130 h (Butler *et al.*, 1994). Since the infection process is slow and may continue for at least a week, the total wetness duration over a 7-d period was considered.

It is also known that intermittent wetness promotes germ tube branching and host penetration. So, if the leaves remain dry for at least 4 h per day during a 5-day period, the number of lesions is about three times greater than with continuous wetness (Wadia and Butler, 1994). Based on this information, a daily Wetness Index (WI) was devised. It increases linearly from 0 to 1 as the wetness period increases from 0 to 20 h, and decreases linearly from 1 to 0.3 as the wetness period increases from 20 to 24 h (Fig. 1).

Inoculum

A spore trap (Seven-day Recording Volumetric Spore Trap, Burkard Manufacturing Company Ltd, Rickmansworth, UK) was operated continuously during the rainy season in groundnut crops at IAC from 1991 to 1993. Daily totals of

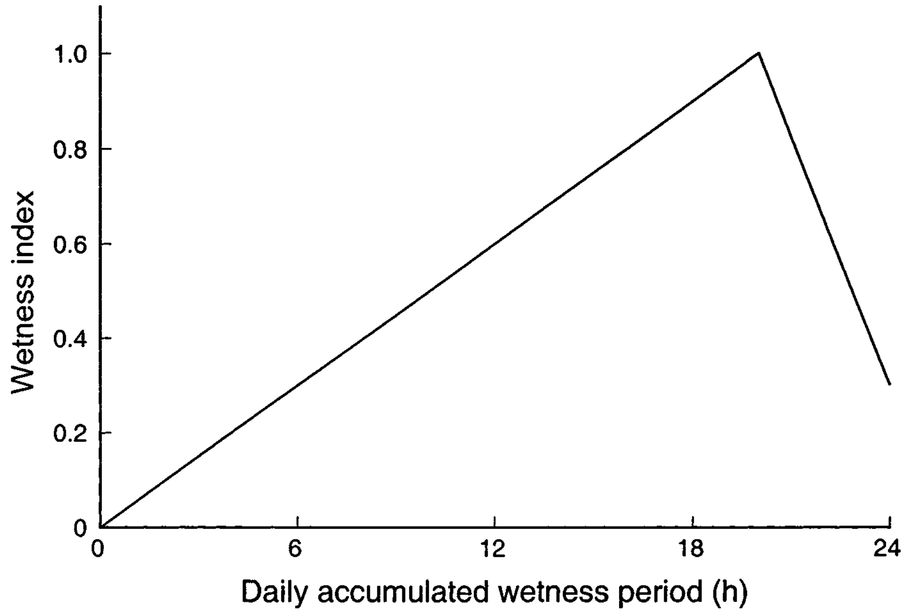

Fig. 1. The relationship between the wetness index and the daily accumulated leaf wetness period. The index increases linearly for daily wetness periods up to 20 h and then decreases because less infection occurs with continuous wetness.

airborne conidia of *P. personata* and *C. arachidicola* were used to assess seasonal changes in the amount of inoculum. Early in the season prior to any visual disease symptoms, very few conidia of these pathogens were found. Typically about one conidium was trapped in a 3-d period which would be sufficient to establish initial (isolated) lesions in the crop, but not to cause serious disease. A rapid increase in the number of airborne conidia was observed and this coincided with the time when one or more leaf spot lesions were found on about 10% of the leaves. Since the quantification of airborne inoculum is difficult, a level of 10% disease incidence was selected as an indirect measure of the time when there is sufficient inoculum to pose a disease threat if other environmental variables are conducive to infection.

WETNESS INDEX EVALUATION

At weekly intervals throughout the 1989, 1990, 1991, 1992 and 1993 rainy seasons, eight 4-week-old potted groundnut plants were inoculated with *P. personata*. The inoculations were made using an atomiser with a spore suspension containing 10^4 conidia ml^{-1}, as described by Butler *et al.* (1994). Four of the potted plants were placed in the crop at IAC and the other four (controls) were maintained wet in a dew chamber at 23 °C for 16 h overnight on five consecutive days. During the daytime the controls were moved to a glasshouse so that intermittent leaf wetness was provided.

After each set of inoculated plants had been exposed to natural weather conditions for 7 d, they were transferred to a glasshouse (with the controls) for a further 14 d for symptom development. The number of lesions was then recorded on main-stem leaves 3 to 5 inclusive (counting from the top of the stem). An 'infection ratio' was calculated, dividing the mean lesion number for exposed plants by that for the controls.

Leaf wetness in the field was monitored with an electronic 'grid' sensor, made in the shape of a groundnut leaflet 6 cm in length and 2.5 cm at the widest point. The sensor was mounted in the crop at the height of the uppermost leaves and wetness, detected by a change in resistance, was recorded at 10-min intervals on a data logger (21X, Campbell Scientific Inc., Logan, UT, USA). Each day, data from the wetness sensor were used to calculate WI. Seven-day totals of WI were calculated to coincide with the periods of exposure of the inoculated plants.

When the infection ratios were compared with the WI totals, a clear pattern emerged (Fig. 2). Whenever the WI total was less than 2.3 the infection ratio was close to or equal to zero. At values greater than 2.3, however, the infection ratio covered a wide range (from zero to 1.7). Infection ratios greater than one were possible because natural conditions may have been more conducive to infection than the controlled conditions. In addition, natural inoculum would have been deposited on the plants in the field but not on the controls. It appears that the risk of leaf spot infection in the field is small when the 7-day WI total is less than 2.3. When the value is greater than 2.3, however, the risk of infection is high, although

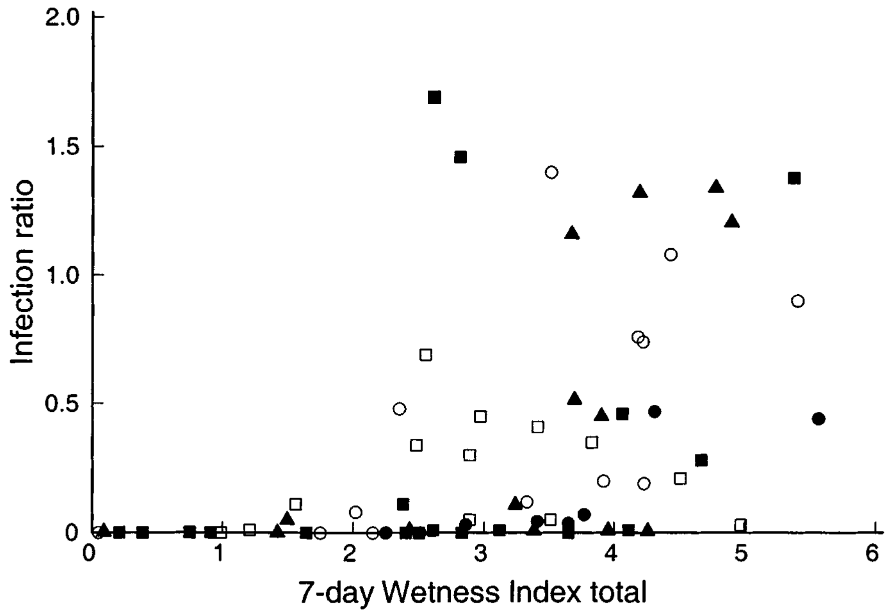

Fig. 2. The relationship between 7-d Wetness Index totals and the infection ratio for inoculated plants exposed to natural conditions in a groundnut crop. Data were collected weekly in the rainy seasons of 1989 (●), 1990 (○), 1991(■), 1992 (□) and 1993 (▲) at the ICRISAT Asia Center, Andhra Pradesh.

other factors not considered here may still affect the number of lesions resulting from a given amount of inoculum.

CRITERIA FOR FUNGICIDE APPLICATION IN THE WBAS

For groundnut crops with a duration of 100–110 d the weather-based advisory scheme (WBAS) was operated from 14 to 85 d after emergence. To decide on making a fungicide application, two criteria were used: the disease threshold and the 7-d WI total.

Disease threshold

At 3- to 4-d intervals, five plants selected at random within the crop were assessed non-destructively for leaf spots. The total number of intact leaflets (four leaflets per leaf) and the number of diseased leaflets on the main stem were counted. Leaflets were considered diseased if one or more leaf spot lesions was present (early and late leaf spots were not distinguished).

The leaf wetness criterion was only considered if there were 10% or more diseased leaflets, otherwise no fungicide was applied.

Wetness Index totals

The daily WI was calculated from the number of hours of accumulated leaf wetness each day (WH), as described earlier. Table 1 gives an example of the procedure for calculating the 7-d WI total.

Fungicide was only applied if the disease incidence exceeded the 10% threshold and the 7-d WI total was equal to or greater than 2.3. When these criteria were met, applications were made at the first opportunity when rain was not expected for at least 12 h.

Successive sprays were not applied within 14 d of each other and the maximum number of sprays in the growing season was three.

Table 1. An example of the calculation of the Wetness Index (WI) total from daily accumulated leaf wetness periods (WH). If WH is 20 h or less, then WI = WH/20. If WH is greater than 20 h, then WI = 4.5 − 0.175WH.

Day	WH (h)	WI
1	8	0.40
2	0	0.00
3	12	0.60
4	16	0.80
5	22	0.65
6	4	0.20
7	10	0.50
WI total		3.15

FIELD EXPERIMENTS

Field trials to test the WBAS were carried out in the rainy seasons of 1992, 1993 and 1994 at IAC, Patancheru and, in 1992, at the Central Research Institute for Dryland Agriculture (CRIDA), Hayathnagar. In 1993 and 1994, experiments were also conducted at the Dryland Farming Agricultural Research Station, ANGRAU, Anantapur (referred to as ANGRAU).

Similar experiments were carried out in all locations, normally with four treatments and four replicates arranged as a randomized block design. A locally popular groundnut cultivar, TMV 2, was used throughout, and the crop was planted with rows 30 cm apart and with 10 cm between plants in the rows. At IAC and ANGRAU the plot size was either 12 × 12 m or 10 × 10 m and final yield was measured in the central 3 × 3 m area. At CRIDA the plot size was 6 × 6 m and final yield was measured in the central 2 × 2 m.

The treatments were as follows:

- no fungicide (control);
- full fungicide protection;
- current recommended farmers' practice (CR);
- fungicide applied according to the WBAS.

The treatment fungicide at IAC and CRIDA was chlorothalonil (3 g L^{-1} water) and at ANGRAU a mixture of Bavistin (1 g L^{-1}) and Dithane M-45 (2 g L^{-1}) was used. The volume of fungicide mixture applied varied between 100 and 400 L ha^{-1}, depending on the crop growth stage. The number of sprays in the 'full protection' treatment varied between sites because applications were not started until disease symptoms appeared. Subsequent applications were made at 15-d intervals at IAC and CRIDA, but less frequently at ANGRAU where there was less disease pressure. The degree of protection also varied and at IAC (normally the wettest site, with greatest disease pressure), disease symptoms persisted even with eight fungicide applications. Dates of planting, dates of fungicide sprays in the WBAS and CR treatments and dates of harvest are given in Table 2.

Outcome

In the WBAS treatment, the number of fungicide applications varied between sites. At IAC, three applications were made in all three years, two applications were made at CRIDA, and either one or two applications were made at ANGRAU (Table 2). The WBAS treatment resulted in significant ($p < 0.05$) increases in pod yield at all sites in 1993 and 1994, but not in 1992 (Table 3).

The current recommended farmers' practice is to make three fungicide applications at fixed intervals; 45, 60 and 75 d after emergence. Comparing the WBAS and the current recommended practice, similar pod and haulm yields were generally obtained at IAC, with slightly better yields in 1992 from the recommended practice. Three fungicide sprays were applied in both these treatments.

Table 2. Dates of sowing, fungicide applications (weather-based advisory scheme (WBAS) and current recommendation (CR)) and harvests in the rainy seasons of 1992, 1993 and 1994 at the ICRISAT Asia Center (IAC), the Central Research Institute for Dryland Agriculture (CRIDA) and the Dryland Farming Agricultural Research Station of the Acharya N. G. Ranga Agricultural University (ANGRAU).

Location	Sowing date	Harvest date	Dates of fungicide application: WBAS	Dates of fungicide application: CR	Total rainfall (mm)
		1992			
IAC	10 July	20 October	6 August 21 August 3 September	3 September 18 September 3 October	420
CRIDA	23 June	21 October	11 August 16 September	7 August 22 August 7 September	419
		1993			
IAC	13 July	23 October	11 August 26 August 10 September	6 September 20 September 5 October	607
ANGRAU†	23 July	27 October	14 October	14 September 29 September 14 October	526
		1994			
IAC	7 July	20 October	8 August 23 August 14 September	30 August 14 September 29 September	537
ANGRAU†	12 August	1 December	1 November	26 October 19 November	222
ANGRAU‡	15 August	1 December	22 October 5 November	—	216

† Exposed site (in a flat open area); ‡ sheltered site (in a small valley with trees).

At ANGRAU, however, fewer fungicide applications were made in the WBAS and similar yields were obtained from both treatments (Tables 3 and 4).

At CRIDA, where only two sprays were applied in the WBAS, there were no significant differences between any of the treatments. This may have resulted, in part, from the small plot size, since there was large variation between replicates.

CONCLUSIONS

Although there was no apparent advantage of the WBAS over the current recommended practice at IAC, the number of fungicide applications were reduced at ANGRAU without any loss of yield. The disease pressure was much higher at IAC than at ANGRAU, so limited fungicide applications were less effective at the former site. At ANGRAU, even a single spray led to significant increases in yield.

Table 3. Mean pod yield (dry weight, kg ha^{-1}) for different fungicide treatments in the 1992, 1993 and 1994 rainy seasons at four sites in Andhra Pradesh.

Site	Treatment			
	No spray	Full protection	Current recommendation	WBAS†
		1992		
IAC	507 (50)‡	780 (19)	788 (74)	666 (54)
CRIDA	1145 (132)	1466 (278)	1577 (360)	1283 (215)
		1993		
IAC	1033 (38)	2047 (161)	— —	1457 (98)
ANGRAU§	1792 (146)	2492 (247)	2609 (324)	2395 (230)
		1994		
IAC	631 (74)	1262 (123)	965 (65)	991 (77)
ANGRAU§	731 (31)	1047 (37)	1095 (24)	1091 (27)
ANGRAU¶	1346 (85)	1764 (35)	— —	1913 (52)

† Weather-based advisory scheme; ‡ data in parentheses are s.e.m.; § exposed site (in a flat open area); ¶ sheltered site (in a small valley with trees).

Table 4. Mean haulm yield (dry weight, kg ha^{-1}) for different fungicide treatments in the 1992, 1993 and 1994 rainy seasons at four sites in Andhra Pradesh.

Site	Treatment			
	No spray	Full protection	Current recommendation	WBAS†
		1992		
IAC	1221 (169)‡	2135 (275)	1884 (219)	1602 (126)
CRIDA	1350 (104)	1956 (301)	1694 (167)	1938 (47)
		1993		
IAC	2260 (212)	4250 (210)	— —	2400 (140)
ANGRAU§	1800 —	2658 —	2629 —	2729 —
		1994		
IAC	1612 (70)	2390 (176)	1910 (206)	1819 (123)
ANGRAU§	1462 (48)	2077 (62)	2149 (45)	2163 (51)
ANGRAU¶	2076 (131)	2650 (55)	— —	2912 (68)

† Weather-based advisory scheme; ‡ data in parentheses are s.e.m.; § exposed site (in a flat open area); ¶ sheltered site (in a small valley with trees).

Although the current recommended practice is to make three fungicide applications at 45, 60 and 75 d after emergence, this is not widely practised in the south of Andhra Pradesh. The results from the experimental station at ANGRAU indicate that worthwhile increases in yield are possible from very limited fungicide applications, and we think the use of the WBAS on farms in the area could be cost-effective in certain years. The scheme would ensure that unnecessary fungicide applications are avoided in exceptionally dry years when leaf spot diseases would not pose a serious threat.

Operation of the WBAS in experimental stations was possible because daily leaf wetness periods could be monitored; this information is not normally available on farms. To address this problem and to carry out on-farm trials, an inexpensive instrument to monitor leaf wetness has been developed for use in remote sites.

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