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Insect pests of pearl millet in Sahelian West Africa - II. *Raghuva albipunctella* De Joannis (Noctuidae, Lepidoptera): distribution, population dynamics and assessment of crop damage

(*Keywords* crop loss diapause millet populations rainfall *Raghuva* Sahel)

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Abstract. Pest surveys in farmers fields were conducted for *Raghuva albipunctella* infestations on pearl millet in Burkina Faso Niger and northern Nigeria in 1980-1983 Field studies on the seasonal fluctuations of moths and diapausing pupae assessment of crop damage and grain yield loss were conducted in Niger The results indicated that *R albipunctella* occurred between latitudes 11 N and 15 N within the Southern Sahel and Sudan bioclimatic zones *R albipunctella* is a univoltine species and off-season carryover is through diapausing pupae in the soil The majority of diapausing pupae (51%) were found at 10-20 cm of soil depth The onset and continuity of rains favourable soil moisture and temperature conditions were key factors in diapause termination duration of post-diapause development and adult emergence Crop damage and grain yield loss were a function of sowing date time of panicle exsertion and the occurrence of critical numbers of adult moths Percentage crop lost varied from 1% to 41% with a mean of 20%

Introduction

After the Sahelian drought of 1968–1972 which resulted in severe food shortages, the region received an abundance of rainfall which was accompanied by severe pest outbreaks Pearl millet (*Pennisetum americanum*, L), the major staple cereal of the Sahelian zone of West Africa, was devastated by infestations of the earhead caterpillar, *Raghuva albipunctella* De Joannis *R albipunctella* has been reported across the Sahel from Mauritania in the west, to Chad in the east, as well as in Ghana, Nigeria and the Sudan (Vercambre, 1978) During the seventies, when outbreaks were most severe, Vercambre (1978) reported yield loss of up to 25% in Senegal and Breniere (1974), in Niger, estimated a loss of 15%

Apart from the studies of Vercambre (1978), very little information has since been accumulated on this pest Gahukar (1984) and Gahukar *et al* (1986) have attempted to put together information collected from unpublished country reports, institute annual reports, and workshops and seminar papers available in the region They concluded that gaps exist in the present knowledge available for a meaningful pest management strategy

The International Crops Research Institute for the Semi-Arid Tropics (ICRISAT) initiated studies on pests of sorghum and pearl millet in West Africa in Senegal in 1976, Burkina Faso (then Upper Volta) in 1979, and Niger and Nigeria in 1980 This paper deals with studies on *R albipunctella* from 1980 to 1986 in the above countries (except Senegal) on the geographical distribution, population dynamics and the relationships between rainfall, soil physical parameters, diapause and subsequent adult emergence The results of field trials designed to evaluate the damage caused by *R albipunctella* are included

Materials and methods

Pest surveys

The geographical distribution of *R albipunctella* (referred to as *Raghuva*) was surveyed in millet crops in farmers' fields Surveys were initiated in 1980 and covered 125 farms in Burkina Faso, 178 in Niger and 34 in northern Nigeria In 1981, the surveys covered 64 farms in Burkina Faso and 38 in Niger and in 1982 and 1983 additional surveys were conducted in a total of 203 farms in Niger Fields were selected at random at 10–40 km intervals depending on their distribution, road accessibility and area to be sampled during each survey

Infestations of *Raghuva* were monitored by observing 150–250 randomly selected millet panicles per farm for the presence of the characteristic spiral damage caused by older larvae The proportion of infested panicles was recorded and damage severity was rated on a scale of 1–5 where 1 = little or no damage and 5 = severe damage

Population studies

From 1983–1986, populations of adult moths were monitored during the crop season (May–October) at the ICRISAT Sahelian Center (ISC), Sadore, Niger by the use of portable light traps equipped with 25 W fluorescent tubes. The traps were placed within millet fields of the research centre and operated daily for 2 h usually between 1900 and 2100 h

During the post-harvest seasons of 1984–1986 (November–May), diapausing pupae in the soil were monitored by carrying out monthly soil sampling in 12 randomly selected 1 × 1 m microplots in millet fields. This was done by excavating and sieving the soil at 5 cm intervals to a

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depth of 30 cm through 2 mm sieves The numbers of diapausing pupae and empty pupal cases in each layer were recorded

In 1984 and 1985, soil thermometers were installed at the soil surface and depths of 5 10 15 20 and 25 cm, with three replications Soil temperatures were recorded daily at 0800 and 1400 h Soil moisture measurements were made every Monday through the year by gravimetric sampling of soil at depths of 5, 10 15 20 25 and 30 cm Daily rainfall was taken from the ISC meteorological observatory located about 600 m from the experimental fields

Crop damage assessment

Three trials were designed to estimate panicle damage and grain yield loss caused by infestations of *Raghuva*

(a) Paired plant analysis In 1982, five millet cultivars (CIVT, Ex-Bornu, Nigeria Composite, Souna from Mali and a local) were sown in 20 m × 20 m blocks at Sadore At the first indication of panicle exsertion, about 500 randomly selected panicles (four to five replicates of 100) were tagged and covered with paper bags for 10 days to prevent oviposition by *Raghuva* An equal number of unbagged panicles was also tagged At harvest the panicles were scored for *Raghuva* infestation (present or absent) and grain yield was recorded Yield loss was calculated based on the formula by Judenko (1972)

(b) Relationship between sowing date and crop damage Earlier studies have indicated that the severity of *Raghuva* damage varies with sowing date and crop phenology (Vercambre, 1978, ICRISAT, 1984, Gahukar *et al* 1986) In order to estimate crop loss as a function of sowing date, crop age and *Raghuva* incidence, date of sowing trials were conducted at Sadore in 1984, 1985 and 1986 in a split plot design with date of sowing (d o s) as the main treatment (19 May, 30 May, 18 June and 3 July) and cultivars as subtreatments (HKBtif, CIVT and Sadore local) The trial was laid out in four replications in plots of 5 m × 5 m Irrigation was initially provided for the first d o s of 19 May

(c) Insecticide trial Quantitative losses were estimated by comparing the grain yields obtained from insecticide treated and untreated plots In 1984 the trial at Sadore was abandoned due to extremely low *Raghuva* infestation In 1985 it was repeated at Chikal (Filingue department in northern Niger), a regular pest hot spot Three cultivars (HKBtif, CIVT and a local) were sown in a split plot design in six replications with cultivars as main plots and insecticide treatment (Decis, decamethrin, 10 g a i /ha) and non-treatment as sub-plots in plots of 8 m × 8 m Four insecticide applications were made at weekly intervals starting at panicle exsertion

For all trials, standard recommended agronomic practices were followed, and the following were recorded days to 50% panicle exsertion, % panicles with eggs, % damaged panicles, damage severity and grain yield at harvest

Results and discussion

Occurrence and distribution

Raghuva occurred within the southern Sahel and Sudan bioclimatic zones, from latitudes 11° N to 15° N, where mean annual rainfall ranges between 400 and 800 mm (Figure 1) This region is also characterized by arenosols

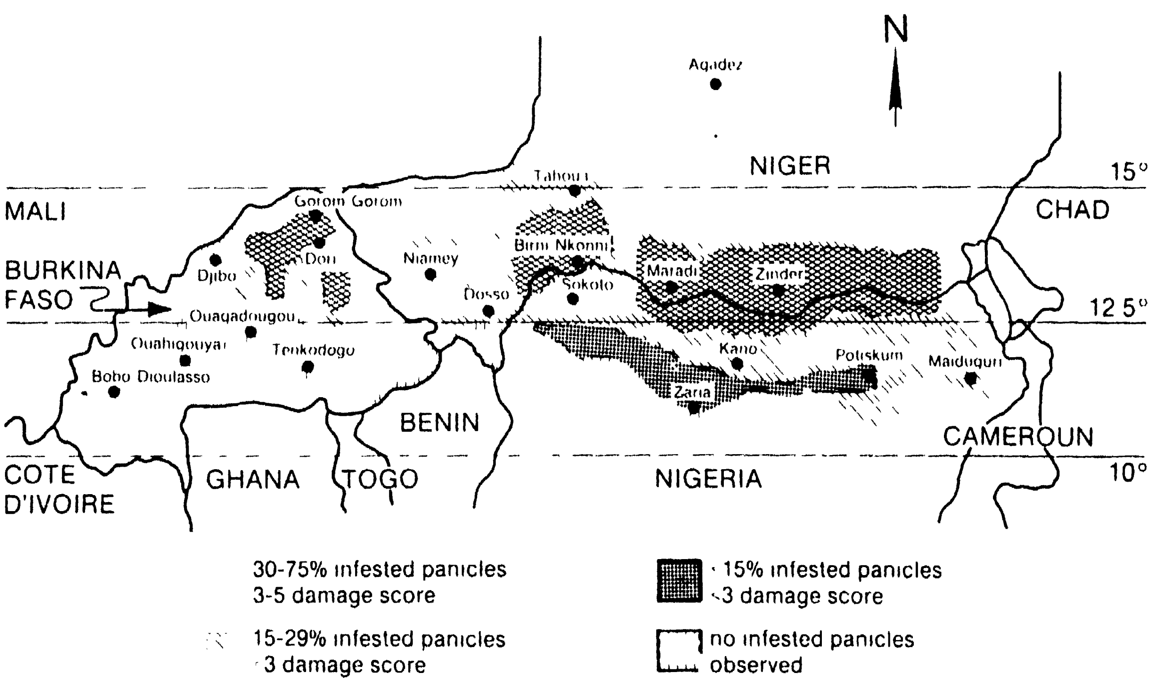

Figure 1 Distribution of the millet earhead caterpillar, Raghuva albipunctella *in West Africa (Burkina Faso, Niger and Nigeria), 1980–83 field surveys*

or coarse textured soils containing more than 65% sand and less than 18% clay (Sivakumar 1986) The southernmost boundary of occurrence was in Nigeria just south of Zaria whereas the northernmost boundary was in Tahoua, Niger It should be noted that these boundaries only reflect the area covered by the present surveys *Raghuva* is known to be present as far north as Agadez in Niger (ICRISAT 1981) Crop infestation was not uniform one field could be devastated while an adjacent field was totally free of infestation This non-uniformity was presumably associated with sowing date and/or crop phenology

In northern Nigeria, infestation was observed just south of Zaria, extending both east (Potiskum and Maiduguri) and west (Sokoto) across the border into the districts of Maradi and Zinder in Niger The zone between Zinder in Niger and Kano in Nigeria and westwards into Niamey (Niger) and Dori and Gorom Gorom in Burkina Faso experienced the most severe infestations (Figure 1) In 1980 81% of the 125 fields surveyed in Burkina Faso were infested by *Raghuva* but only 18% of the panicles were damaged The most severe infestation was observed in Niger where 95% of the 178 fields surveyed in 1980 were infested and a mean of 34% of the panicles were damaged In 1981 38 farms were surveyed and the corresponding figures were 97% and 25% respectively But in 1982 and 1983 a decline in infestation was observed Less than 50% of the 203 farms examined had *Raghuva* infestation and only 14% of the panicles were damaged

Soil distribution of diapausing pupae

Raghuva diapauses in the pupal stage (Vercambre, 1978) The prepupal sixth instar larvae crawl from the panicle fall to the ground and penetrate into the soil Pupation occurs 2–3 days later

The distribution of pupae differed between soil layers Most pupae (51%) were found in the 10–20 cm soil layer Sixteen percent were located in the 0–10 cm zone and 33% in the 20–30 cm zone Vercambre (1978) reported that the majority of pupae (86 4%) were located in the first 10 cm of the soil It is now known that the majority of larvae pupated 10–15 cm deep in heavy soil (clay/loamy) and 15–25 cm in sandy soils (Gahukar *et al*, 1986)

Studies undertaken at Sadore in 1985 and 1986 also showed that a higher proportion of pupae in the upper soil layers (0–10 cm) were within 25 cm of plant hills while deeper lying pupae were located in the area between plants

Population dynamics

Adult moth population Results from 4 years (1983–86) of monitoring moth populations at Sadore show that *Raghuva* is univoltine (Figure 2) and it goes into obligatory diapause at the end of the crop season This confirms earlier studies in Senegal (Vercambre, 1978), eastern Niger (Guevremont, 1981, 1982) and Burkina Faso (ICRISAT, 1981, 1982)

Moth emergence from the soil usually started in mid-July, 40–50 days after the first 'good rains' (15–25 mm,

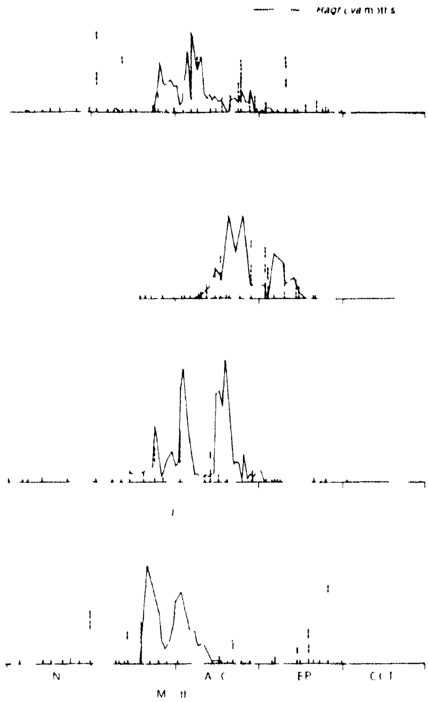

Figure 2 Daily rainfall distribution and light trap catches of Raghuva albipunctella *1983–86 ISC Sadore Niger*

Dancette, 1979) of the season (Figure 2) Vercambre (1978) reported a range of 32–37 days in Senegal In 1983 and 1984, the first rains at Sadore fell in early May but the first good rains occurred respectively on 4 June (18 6 mm) in 1983 and 31 May (20 9 mm) in 1984 First moth captures were recorded 41 and 43 days later respectively on 15 July 1983 and 13 July 1984 (Figure 2) However in 1985, a delay in the arrival of the first good rain (19 4 mm on 18 June) resulted in a corresponding shift in adult emergence with first moth captures occurring 49 days later on 6 August In 1986 although good rains (26 mm) occurred early on 18 May and moths were first recorded 51 days later (8 July), emergence lasted for only 2 days No moths were observed for 12 days between 10 and 21 July inclusive There was, however, a dry spell between 29 May and 15 June during which four minor showers, each of less than 2 mm, were received Subsequent and continued moth emergence only resumed on 22 July, 53 days after the rainfall of 29 May or 67 days after the first good rainfall of 18 May

Pupal population The population of diapausing pupae declined as the dry season progressed from November to May Estimates from the microplots ($1 \times 1 \times 0\ 3$ m) showed a decrease from 10 pupae m^{-3} of soil in November 1985 to 2 m^{-3} in May 1986 This decrease in numbers is associated with the mortality of diapausing pupae The number of surviving pupae (measured in terms of number diapausing individuals v empty pupal cases) was much lower in the upper layer (0–15 cm), (Figure 3, a–c) than in the lower layer (15–30 cm) (Figure 3, d–f) and was closely associated with changes in soil temperature and moisture at different depths from November to May (Figures 4 and 5). In the top 5 cm, no diapausing pupae were recovered in April and May At 15 cm depth and above, mortality increased to > 60% from February to May Mean soil temperatures during these months were high (Figure 4) with maxima often exceeding 45° C Soil moisture content was also at its lowest during these months (Figure 5) At 20 cm and below, pupae were less affected by rising temperatures or low soil moisture content

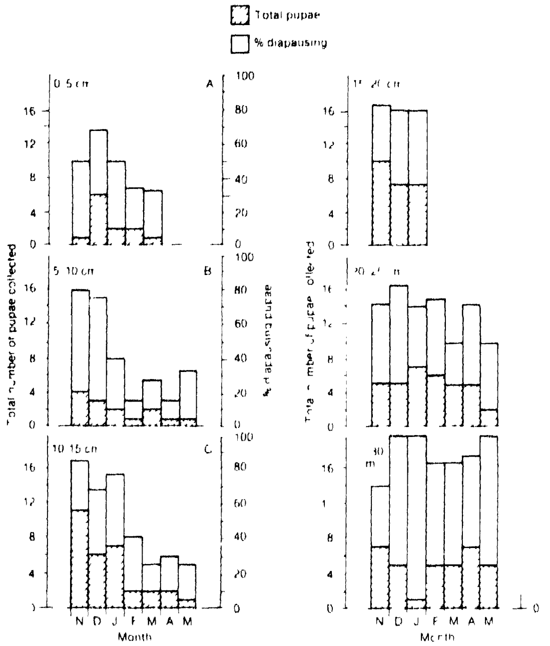

Figure 3 Fluctuation and survival of soil populations of Raghuva *pupae, 1984–85 dry season, ISC, Sadore, Niger*

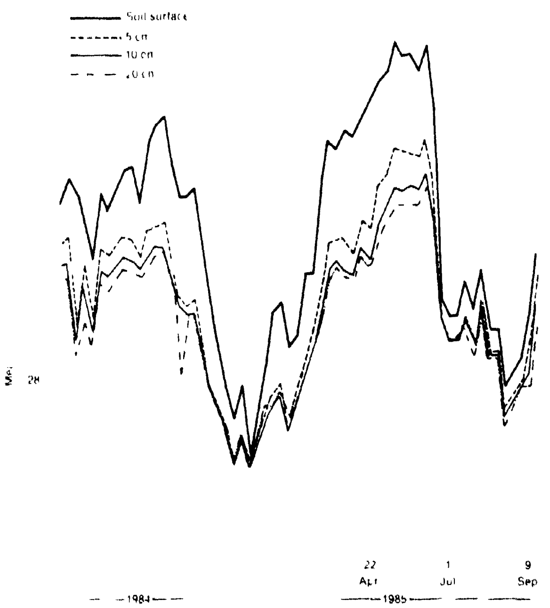

Figure 4 Week day mean soil temperatures at different depths, 1984–85, ISC, Sadore, Niger (mean of 3 replicates)

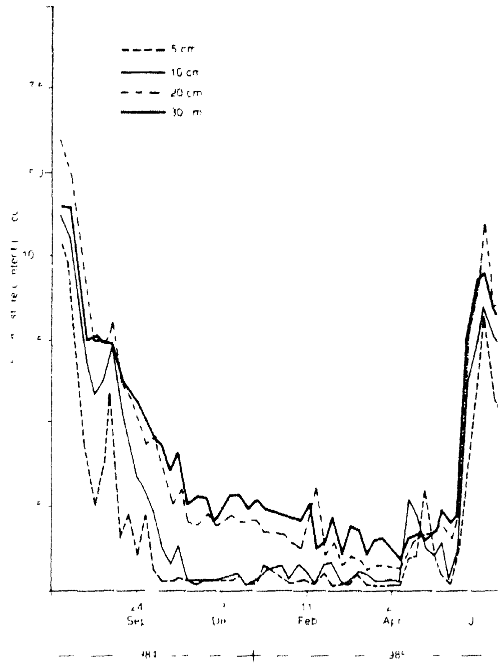

Figure 5 Weekly soil moisture content at different soil ‹ 1984–85, ISC, Sadore, Niger (mean of four replicates

Crop damage assessment

(a) Paired plant analysis The highest yield loss (1 was recorded on CIVT compared to the later maturin cultivar (0·8%) (Table 1) The other three cultivars, ti with similar growth cycles as CIVT, were less dam The infestation on bagged heads is attributed to ovipc before bagging or after bags were removed

(b) Relationship between sowing date and damage Adult moths were first recorded in light trap 23 July and continued appearing for 42 days (Figu Days to 50% panicle exsertion in all cultivars occur different times and was related to sowing dates The maturing local cultivar sown at the first d o s on 19th had the highest infestation (panicles with eggs 44 damaged panicles 30%) For this sowing date, the n date of 50% panicle exsertion (8 August) coincided the period of peak moth emergence This cultivar had lowest infestation when sown on other dates.

HKBtif, an early maturing cultivar, had relatively panicle damage (9·2%) in the first d o s but it regist the highest damage on the second (30 May) and t (15 June) d o.s (37·5% and 28·3% respectively) · mean dates of 50% panicle exsertion of 8 August 15 August respectively. No panicle damage was obser in any cultivar sown at the last d.o.s. on 3 July. At sowing date, panicle exsertion in all cultivars occu during a period (4–13 September) when moth populat was almost nil

These observations indicate that panicle damage highly dependent upon date of sowing, crop phenology maturity cycle and the synchronization between cult panicle exsertion and adult moth emergence

Table 1. Assessment of grain yield loss in five millet cultivars due to Raghuva albipunctella *attack, Sadore, Niger 1982*

Entry	Days to 50% panicle exsertion	No. of panicles in samples		% Infested panicles		Damage severity†		Grain yield (g/panicle)		Estimate yield loss (%)
		Bagged	Unbagged	Bagged	Unbagged	Bagged	Unbagged	Bagged	Unbagged	
CIVT	43	475	515	7·4	64·4	1·0	3·5	32·9	23·9	14·9
Ex-Bornu	45	395	493	6·7	56·6	1·0	2·0	15·6	13·9	6·6
Nigeria Composite	43	505	407	1·7	57·4	1·0	2·0	14·2	12·8	4·6
Souna (Mali)	44	387	416	5·1	44·4	1·0	2·0	15·8	14·5	4·8
Local	52	435	390	2·2	7·8	1·0	2·0	14·6	14·3	0·8
Mean	45·4	439·4	444·2	4·6	46·1	1·0	2·1	18·6	13·8	
S.E. (m) ±	1·6	26·1	35·5	1·1	10·1	0	0·4	3·5	3·1	

†Measured on a 1–5 scale, where 1 = very low to zero, and 5 = high severity.

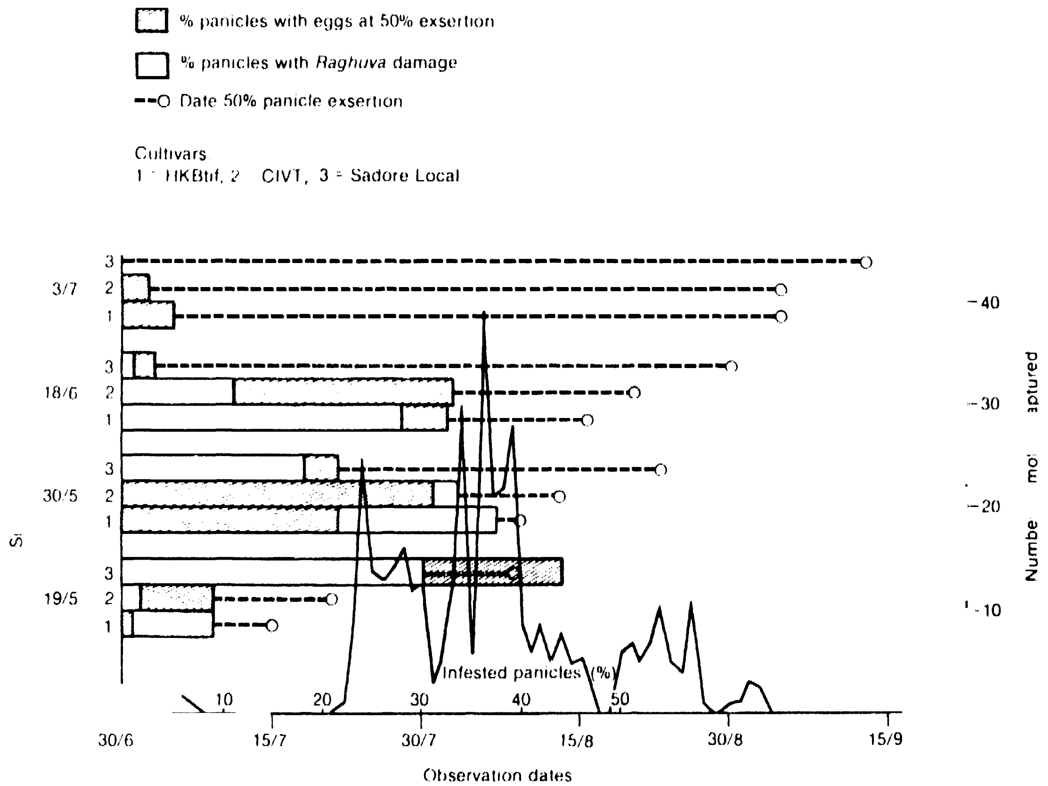

Figure 6. Relationship between sowing date, cultivar, Raghuva *moth emergence and crop infestation, 1986, ISC, Sadore, Niger.*

(c) Insecticide trial. The results of this trial confirm earlier observations made in these studies. Panicle damage by *Raghuva* was highest in the early maturing HKBtif (53%) which also corresponded with the highest loss in grain yield (41%) (Table 2). It was lowest in the later maturing local cultivar (8%) while in CIVT it was 17%. The cultivars HKBtif and CIVT did not differ significantly in time to 50% panicle exsertion but they suffered different levels of panicle damage.

Conclusion

The observations and results obtained in these studies present an interesting picture when viewed within the context of insect pest/host plant/environment interactions. The results indicate that soil temperature and moisture content are vital factors in regulating the survival of diapausing pupae. They also indicate that there is a close relationship between moth emergence and the onset of rains and that soil moisture is a key factor in diapause termination. The increase in soil moisture content and the reduction in soil temperature at the onset of rains is usually dramatic, occurring at a much higher rate in the upper than in the lower soil layers.

However, while the onset of rains, increase in soil moisture and decrease in soil temperature may be key factors in diapause termination, continued development after diapause termination (post-diapause development) i

Table 2 Assessment of crop loss caused by infestation of Raghuva albipunctella *in three millet cultivars, Chikal, Niger, 1986*

Entry	Treatment	Days to 50% panicle exsertion	Panicles with eggs (%)	Damaged panicles (%)	Damage severity‡	Yield (kg/ha)	Yield loss (%)
HKBtif	Protected†	46	4	9	1 0	1840	41
	Unprotected	44	54	53	4 2	1090	
CIVT	Protected	48	4	9	1 0	2310	17
	Unprotected	46	33	22	2 8	1920	
Local	Protected	59	2	8	1 2	1650	8
	Unprotected	58	11	15	1 8	1520	
Mean		50	15	19	2 0	1720	
S E ±		3 7	1 9	3 3	0 1	84	

†Protected with Decis, 10 g a i /ha
‡Measured on a 1–5 scale, where 1 = zero to low severity, and 5 high severity

apparently dependent on uninterrupted favourable temperatures and soil moisture content within the limits necessary for growth and development This may explain why a delay in the arrival of rains in 1985 resulted in a shift in moth emergence that year and why the prolonged early-season dry spell in 1986 caused an interruption in moth emergence

The results also indicate that the prepupal progeny from moths emerging early, in mid-July are more likely to encounter favourable soil moisture in the upper soil layers (e g 13 4 cc/cc at 10 cm on 26 August 1985 Figure 5) Progeny from adults emerging later, in August, would need to penetrate deeper, as soil moisture at 10 cm dropped from 13·4 cc/cc on 26 August to 3 7 cc/cc on 30 September whereas at 20 cm it remained at 6 3 cc/cc

The pattern of moth emergence seems to correspond to populations of pupae at different soil depths Diapause termination would tend to occur at different times in the various soil layers as moisture increases to the required threshold The fluctuations in moth emergence are thus partly a reflection of the time of onset of diapause termination and partly due to variations in soil temperature and moisture content at various depths during post-diapause developments The level of crop infestation will subsequently depend on a synchronization of the occurrence of critical numbers of adult moths and the period of cultivar panicle exsertion the physiological growth stage preferred by ovipositing females

The region of occurrence of *Raghuva* (loose, sandy soils with less than 18% clay content) corresponds to characteristics of the biology of the pest which requires penetration into the soil by the prepupal larvae, survival of diapausing larvae and subsequent adult emergence. The same factors (mainly rainfall) that govern early seasonal growth and development of the pest population also condition and ensure the presence of its nutritional requirements in the cropping system.

These studies underline the importance of a knowledge of the interaction between the physical and biological environments of insect pests and their hosts. They emphasize the need for the collection of minimum data sets over several years in order to be able to quantify the major factors required for models of agroecosystems that are essential for designing pest management programs

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