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The effect of soil temperature, moisture and nitrogen on *Striga asiatica* (L.) Kuntze seed germination, viability and emergence on sorghum (*Sorghum bicolor* L. Moench) roots under field conditions

M.A. OSMAN, P.S. RAJU and J.M. PEACOCK
International Crops Research Institute for the Semi-Arid Tropics, (ICRISAT), Patancheru, Andhra Pradesh 502 324, India

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Abstract

Experiments were conducted in a Striga-sick field to study the effect of soil temperature, moisture and nitrogen on Striga parasitism on sorghum. Striga seeds contained in nylon bags and buried at 2 cm in the soil, were exposed to different temperature and moisture treatments. Clear polythene, hay mulch and bare soil treatments were used to vary soil temperature. These treatments gave mean maximum temperatures of 60°, 48° and 37°C, respectively at 2-cm soil depth. Irrigation levels of 0, 30 and 60 mm were applied to change soil moisture. Striga seed germination, viability and emergence were studied. After 34 days of preconditioning, the exhumed Striga seeds from polythene-covered plots (solarized plots) did not germinate or retain viability when these seeds were exposed to sorghum root exudate. However, seeds similarly buried under hay mulch or bare soil, with mean maximum soil temperatures of 48° and 37°C, respectively, had similar germination and viability percentages. Of these 75% germinated and 85% of them were viable, regardless of the temperature treatment. Although seeds stored at high temperature and humidity (solarization) were killed, more Striga plants emerged under the polythene treatment compared to hay mulch and bare soil treatments. The observed Striga plants in the polythene mulch treatment were, therefore, assumed to have come from deeper layers where solarization was not effective. Irrigation treatments did not have significant effects on Striga seed germination and viability, but a slightly higher number of plants emerged at 60-mm irrigation level than at 30-mm and 0-mm. Striga emergence, on the other hand, was directly related to the rate of N application. Nitrogen rates of 0, 25, 50 and 100 kg ha^{-1} resulted in the emergence of 11, 34, 38 and 40 Striga plants per plot, respectively. Despite the high infestation at high N levels, sorghum plants did not show a loss of vigor. Nitrogen application, therefore, does not reduce Striga incidence, but seems to neutralize the harmful effects of Striga without reducing the extent of parasitism.

Introduction

Striga asiatica (L.) Kuntze is a root parasite that causes serious damage to agronomically important crops such as sorghum, pearl millet (*Pennisetum glaucum* (L.) R. Br.), corn (*Zea mays* L.), rice (*Oryza sativa* L.) and sugar cane (*Saccharum officinarum* L.). In the semi-arid tropics where sorghum is an important food for human consumption, *S. hermonthica* (Del.) Benth. (African species) and *S. asiatica* (Asian species), which are germinated by stimulants produced by host roots, are major yield reducers (Doggett, 1965, 1984; Parker, 1984; Vasudeva Rao *et al.*, 1989). For example, heavy infestation of *S. hermonthica* in Sudan (Hamdoun and El Tigani, 1977), Ethiopia (Brhane and Yilma, 1980) and countries in West Africa (Doggett, 1988) forced a large number of farmers to abandon their fields. In India, recent studies have predicted an annual loss of 53,000 t of sorghum grain due to *S. asiatica* infestation (Vasudeva Rao *et al.*, 1989).

In general, Striga seed will not germinate unless certain conditions are met. Musselman (1980) reported that Striga seeds would remain dormant until they were exposed to periods of warm dry conditions and these seeds became responsive to germination stimulants after pretreatment in moist warm conditions. Kust (1963) reported that *Striga asiatica* seeds stored at 31°, 24° and 4°C at high humidity (100% RH) became responsive to a stimulant produced by corn (*Zea mays* L.) and had the highest germination percentages after 8, 32 and 40 weeks, respectively. When the same seeds were stored at 31°C and 100% relative humidity, both germination and viability were reduced. Also, Babikar *et al.* (1987), Vallance (1950) and Andrews (1945) reported that excessive soil moisture reduced Striga infestation.

Increased Striga infestation levels are often observed in soils low in fertility. Several researchers (Agabawi and Younis, 1965; Bebawi, 1981; Last, 1960; Mathur and Mathur, 1967) investigated the effect of various sources and levels of nitrogen on Striga growth and development, with varying results. In most cases, nitrogen fertilizers increased host tolerance to the Striga attack without apparent reduction in parasite infestation. However, most of the available data are based on studies conducted under controlled environments.

The temporal and spatial fluctuations of Striga incidence, particularly under field situations, is believed to be influenced by soil temperature, moisture and soil fertility. The effect of these factors on Striga infestation has not been sufficiently studied under field conditions. It is believed that identification of the optimum field conditions influencing Striga growth and development is a prerequisite for its control. The present study investigates the effect of soil temperature, moisture (used as preconditioning treatments) and nitrogen (applied during crop sowing) on *Striga asiatica* germination, viability and emergence on sorghum.

Materials and methods

Two field experiments were conducted at ICRISAT Center during the 1988 rainy season. A Striga-sick field having a silty, clay loam (hyperthermic-typic-pellustert) soil was used. Details are given below.

Experiment I

Effect of soil temperature and moisture

These two treatments were used for preconditioning Striga seeds, whether artificially sown or naturally existing in the soil, and were carried out 34 days before sorghum was sown. To test the effect of soil temperature and moisture on Striga germination, viability and emergence, 4 × 1.2-m plots were selected. One-year-old Striga seeds, with 85–90% germination, were obtained and mixed with fine sand at a ratio of 10 g Striga seeds per kg of sand. On 14 May 1988, the plots were hand sown with this Striga-sand mixture at a rate of 0.9 kg ha^{-1}. A hand-held garden scrabbler was used to uniformly mix the Striga seeds into the top 5-cm soil. At the same time, samples of these seeds were placed in small nylon bags (3 × 5 cm), tied with 20-cm long retrieval wire strings and buried at a soil depth of 2 cm in each plot so the seeds would be preconditioned in their natural habitat. These nylon bags were resistant to degradation by soil microorganisms and allowed free passage of soil solutions to the seeds. Clear polythene (solarization), and hay mulch treatments were used to modifiy soil temperature giving high and low soil temperatures, respectively, compared to bare soil (control). The polythene sheets (0.125 mm thick, 2 m wide and 5 m long) were laid on pre-irrigated bare, well-tilled soil, spread close to the ground, and their edges were anchored in the soil to prevent heat loss and wind blowing away the plastic covers. Soil temperature was lowered by laying about 5 cm of thick grass straw on bare soil plots similar to those mentioned above. The layer of hay mulch was strapped to the soil to prevent wind-disturbance by using jute string and bamboo sticks driven into the soil around the edges of the plots.

Irrigation treatments were given to the same plots described above, using levels of 0, 30 and 60 mm of water. Except the controls, which were nonirrigated but either mulched or left bare, all plots were given two irrigations at 10-day intervals. Soil moisture contents, taken a day before and after each irrigation at 15- and 30-cm soil depths, were measured using the gravimetric method. Because soil moisture contents at these two depths were almost identical, only soil moisture at a depth of 15 cm was reported. The soil moisture contents are presented in Tables 1 and 2.

To measure soil temperature, 36 copper constantan thermocouples were buried at 2- and 10-cm soil depths in two replications. These thermocouples were connected to a field micrologger, model CR 21× (Campbell Scientific Inc., Logan Utah). The micrologger was programmed to store average soil temperature every 2 h. The data were transferred every 3–4 days to a computer for analysis.

The mean maximum soil temperature recorded at a depth of 2 cm in the polythene-, bare-soil and hay-mulch treatment was, 60°, 48° and 37° respectively, during the study period (Fig. 1a). At 10-cm soil depth, the mean maximum soil temperatures were 50°, 37° and 31°, respectively, for the above-mentioned soil treatments (Fig. 1b). Mean minimum soil temperature for polythene-, bare-soil and hay-mulches at a soil depth of 2 cm were 31°, 28° and 27°C respectively (Fig. 2a) and at 10-cm depth, the same mulch treatments showed minimum mean soil temperature of 34°, 31° and 29°C, respectively (Fig. 2b).

Table 1. Mean soil moisture content (v/v) across all soil treatments at 15-cm depth taken a day before and after irrigation

Irrigation level (mm)	Soil moisture content (v/v)	
	Before irrigation (%)	After irrigation (%)
0	15.0	14.0
30	13.8	24.1
60	14.5	28.0
SE	±3.4	±1.5
CV (%)	6.7	4.6

Table 2. Mean soil moisture content (v/v) across all irrigation treatments at 15 cm depth in polythene-, hay- and bare-soil treatments taken a day before and after irrigation

Soil treatment	Soil moisture content (v/v)	
	Before irrigation (%)	After irrigation (%)
Polythene	15.5	23.3
Bare	12.9	16.3
Hay	15.4	26.6
SE	±1.92	±3.28
CV (%)	6.4	9.9

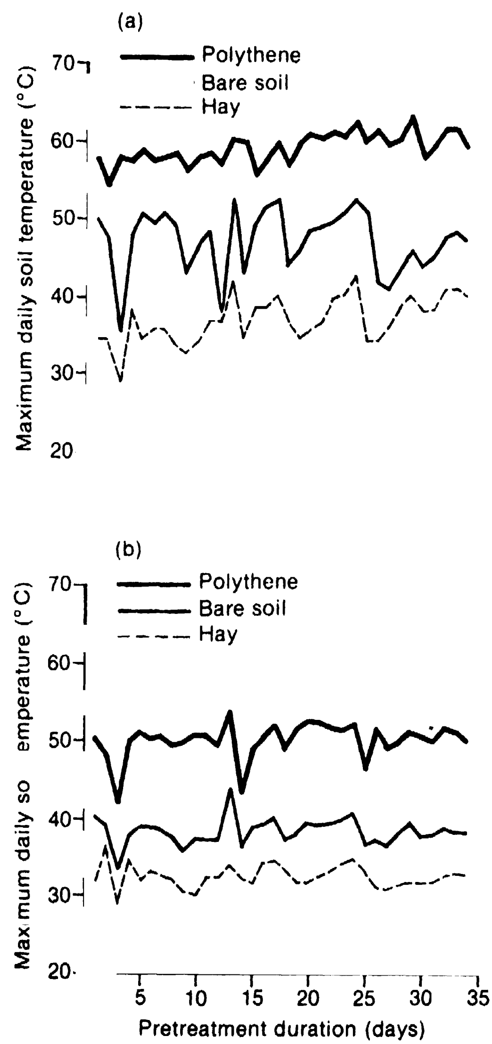

Fig. 1. Maximum daily soil temperatures recorded at 2 cm (**a**) and 10 cm (**b**) from surfaces of polythene-, hay- and bare-soil mulch treatments during the study period.

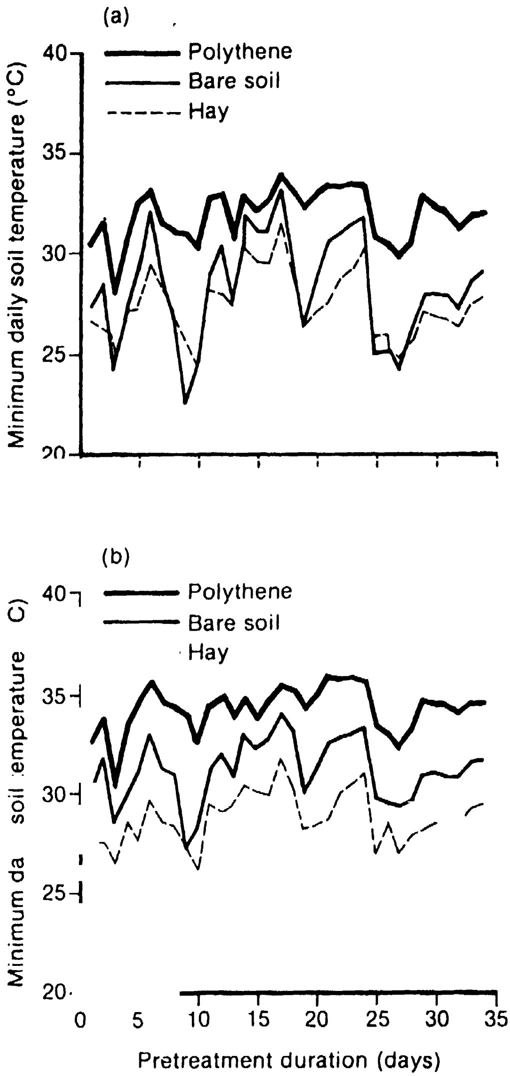

Fig. 2. Minimum daily soil temperatures recorded at 2 cm (**a**) and 10 cm (**b**) from surfaces of polythene-, hay- and bare-soil mulch treatments during the study period.

Rainfall during the study period was recorded using a rain gauge placed in an adjacent field. The total rainfall recorded for the months of June, July, August and September 1988, was 109 mm, 236 mm, 215 mm and 169 mm, respectively. The normal rainfall in ICRISAT for the same months is also shown (Table 3).

A factorial experiment in randomized complete block design with four replications was used. Each temperature-irrigation treatment was randomly assigned to 4 × 1.2-m plots.

Table 3. Total montly rainfall at the study area in 1988 compared to the long term average monthly rainfall in ICRISAT

Month	Total rainfall (mm)	
	1988	Normal
June	109.3	115.5
July	236.3	171.5
August	215.3	156.0
September	169.2	181.0
Total	730.1	624.0

Germination and viability tests

Just before the monsoons started (13 June, 1988), the temperature and moisture treatments were terminated by removing the polythene and hay mulch covers. The nylon bags containing Striga seeds were recovered after 34 days of preconditioning under the different soil temperature and moisture treatments. These seeds were tested for germination and viability.

In a standard germination test, the exhumed Striga seeds were surface sterilized with a 1% NaOCl solution for 5 min, washed with distilled water until the chlorine odor disappeared, air dried for 4–5 h and sprinkled on small glass fiber filter paper discs (7 mm in diameter), using the procedure described by Vasudeva Rao (1985). About 30 seeds were sprinkled on each disc and these discs were replicated four times in each petri dish.

Root exudate was obtained by growing seedlings of a Striga-susceptible sorghum genotype (CSH 1) in prewashed and heat-sterilized quartz sand. The stimulant was extracted by using the 'double pot technique' developed by Parker *et al.* (1977).

Thirty microliters of freshly extracted sorghum root exudate was applied on each disc using a standardized syringe micropipette with disposable plastic tips. Then the discs were placed in petri dishes, sealed in polythene bags and incubated in the dark at 35°C for 24 h. The seeds were assumed to have received sufficient preconditioning in the field, so further pretreatment was not imposed to render the seeds responsive to the stimulant. At the end of the incubation period, the number of germinated Striga seeds per disc were recorded as a percentage of the total number of seeds on that disc. Radicle exertion (0.1–0.2 mm) was used as a criterion for Striga germination.

In that viability test, small discs similar to those used for the germination test, sprinkled with similar amounts of seeds, were used. Each disc was moistened with 25 μL of triphenyl tetrazolium chloride (TR) solution prepared as described by Kust (1963). The seeds were incubated in darkness as described for germination. Because Striga seeds stored in hot humid conditions may undergo a 'wet dormancy' state and such seeds respond to germination stimulants if dried (Vallance, 1950), several viability tests were conducted on the same seeds (after allowing them to dry at room temperature for several months) recovered from the field. These tests nullified the existence of this 'wet dormancy' phenomenon since viability of Striga seeds remained the same.

Counts of viable seeds were made at the end of the incubation period. According to Kust (1963), viable seeds varied from light red to brick-red, while non-viable seeds remained light brown. Because of the small size of Striga seeds, this procedure was not adequate to give reliable counts. Therefore, the seeds were squeezed with forceps and were scored on the basis of the color of the semi-liquid material that oozed out. Thus seeds were scored viable if reddish-brown liquid oozed out and non-viable if the liquid was colorless.

In both germination and viability tests where counts were recorded as percentages, the data were arcsine transformed to obtain a valid analysis of variance.

Experiment II

Nitrogen treatments

The effect of nitrogen on Striga emergence was evaluated in plots that were identical in size to those used in Experiment I. The field was pretested for residual available nitrogen before the treatments were applied. The soil analysis showed a mean nitrogen content of about 20 kg ha^{-1} in the top 30 cm.

Using urea (46-0-0) as the nitrogen source, amounts of 0, 25, 50 and 100 kg ha^{-1} were added to the soil. These rates were given as a basal dose which was added into the top 5 cm.

A randomized complete block design with four replications was used. Each nitrogen treatment was applied to 1.2 × 4.0-m plots and these plots were randomized within replications.

Test for Striga emergence in response to temperature, moisture and nitrogen treatments

On 13 June 1988, all plots in Experiment I (immediately after the polythene and hay treatments) and Experiment II were hand sown with a Striga-susceptible sorghum hybrid (CSH 1). Seed beds were prepared by hand using a pickax. Thus each plot (1.2 × 4.0-m) consisted of 4 rows, 30 cm apart and 4 m long. After seedling establishment, the plots were thinned leaving 10 cm between plants. Shoot pests were controlled by applying carbofuran (2,3- dihydro-2,2-dimethylbenzofuran-7-yl methylcarbamate) to the soil at the rate of 40 kg ha^{-1} and no fertilizer was used in Experiment I (see temperature and moisture treatments).

Striga shoots started to emerge above the soil surface about 35–40 days after sowing. Counting of emerged Striga plants was started 2 weeks after the emergence of the first Striga plants and at weekly intervals thereafter. Because of border effects, counts were not made on a 30-cm wide strip (the outer 2 rows and 30 cm at the ends) around each plot. Thus the data collected were based on 0.6 × 3.4-m plots. Striga plants were not removed (except the dead ones) after each count, therefore, the plants that emerged (dead or alive) were recorded for each plot to get the cumulative total of Striga emergence to that date. These counts were compared at the end of the season and the highest number was taken to estimate the total number of the parasite shoots that emerged in that plot. Similarly, the number of Striga plants that died were recorded. The data were transformed using log (x + 1), where (x) was the final number of shoots recorded per plot.

Results

Analysis of the temperature and irrigation combination treatments showed that the interaction was non-significant ($P > 0.05$) regardless of the parameter considered. The temperature treatment always gave significant effects ($P < 0.01$). Therefore, the results are presented separately.

Effect of soil temperature on Striga germination, viability and emergence

The effects of soil temperature on Striga germination and viability are shown in Table 4. These results show that seeds exposed to solarization (polythene), with its associated effects such as high temperature (60°C) and humidity and anaerobic conditions, did not germinate and were non-viable after 34 days of pretreatment in the field. At 48° and 37°C (bare and hay mulch treatments, respectively, Fig. 1a), however, seed germination and viability were high and similar. In these treatments, about 75% of the seeds germinated in the laboratory and 87% of these seeds were viable (Table 4).

Soil temperature also had a significant ($P < 0.01$) effect on Striga emergence. The results show that about 55, 31, and 15 plants per plot emerged in the polythene-, bare-soil and hay-mulch treatments, respectively (Fig. 3a).

While emergence of high numbers of Striga plants in the polythene treatment confirms earlier laboratory findings that high temperature promotes Striga emergence, it contrasts the earlier findings from the same plots (Table 4) where there was a lack of germination and viability in the recovered seeds. This phenomenon is discussed later in this paper.

Effect of soil moisture on Striga germination, viability and emergence

There was no effect of irrigation levels on Striga germination and viability (Table 5). Germination

Table 4. Germination and viability of Striga seeds in response to soil temperature (as obtained under polythene-, hay- and bare-soil mulch treatments)

Soil treatment	Germination[a] (%)	Viability (%)
Polythene	0.0 (0.0)[b]	0.0 (0.0)
Bare	75.1 (60.1)	87.8 (69.8)
Hay	73.5 (59.1)	87.1 (69.0)
SE	±1.54	±1.75
CV (%)	5.5	5.3

[a] Striga seeds were buried at 2 cm soil depth for 30 days.
[b] Arcsine transformed data are shown in parentheses.

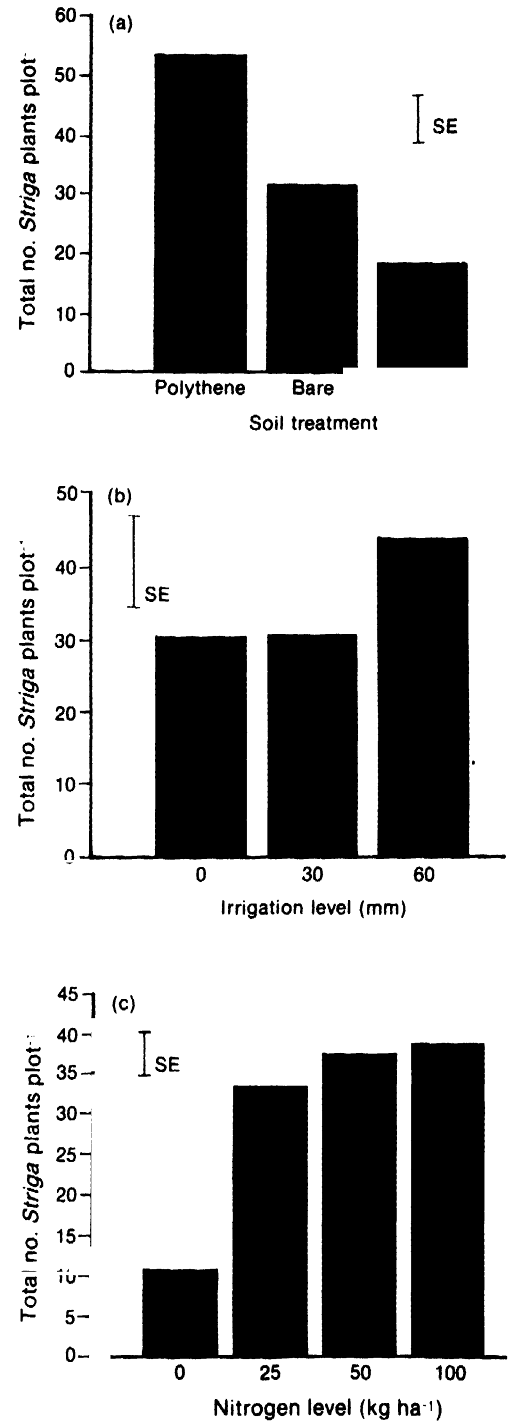

Fig. 3. Total number of emerged Striga plants in soils previously exposed to: the polythene-, hay- and bare-soil mulch treatments (**a**), three different irrigation levels (**b**) and four different nitrogen fertilizer rates (**c**).

Table 5. Germination and viability of Striga seeds in response to different levels of irrigation

Irrigation level (mm)	Germination[a] (%)	Viability (%)
0	50.2 (40.2)[b]	58.3 (40.4)
30	48.4 (39.0)	57.8 (45.8)
60	50.0 (40.0)	58.9 (46.8)
SE	±1.28	±2.10
CV (%)	4.5	6.3

[a] Striga seeds were buried at the top 2 cm depth for 34 days.
[b] Arcsine transformed data are shown in parentheses.

and viability of seeds were 48–50% and about 59%, respectively, across all irrigation levels. However, more Striga plants emerged in plots pre-irrigated with 60 mm of water compared to plots receiving 0- and 30-mm (Fig. 3b). Forty-three Striga plants emerged at the 60-mm irrigation level compared to 30- and 29 plants at 30- and 0-mm levels. But again these differences were not significant (standard error ±12.0). The average soil moisture content (taken after the irrigations) during the pretreatment period was 14, 24 and 28% (v/v), respectively, for 0, 30 and 60 mm water application (Table 2).

Effect of nitrogen on Striga emergence

When nitrogen rates of 25, 50 and 100 kg ha^{-1} were applied to the soil (in addition to a residual N of 20 kg ha^{-1}), the number of Striga plants that emerged per plot increased (Fig. 3c). There was no significant difference between these treatments. However, there were significantly ($P <$ 0.01) fewer emerged Striga plants when no nitrogen (control) was added. Despite the relatively high infestation at the high nitrogen levels, there was no apparent loss of vigor in plants growing on these plots.

Discussion

Striga seeds buried 2 cm below the soil surface in the polythene treatment neither germinated nor were they viable. At this depth, mean maximum daily soil temperature was over 60°C (Fig. 1a) and the soil was always wet because water vapor that evaporated was trapped by the polythene cover and was again precipitated on the soil surface. Higher soil moisture increases soil heat conductivity and seed sensitivity to high temperatures (Horowitz *et al.*, 1983). Kust (1963) reported that prolonged storage of Striga seeds under hot humid conditions, similar to those observed under the polythene, killed the seeds. However, Vallance (1950) argued that Striga seeds under such conditions did not necessarily lose viability but underwent a 'wet domancy' stage. This dormancy was reversed by drying the seeds and subsequently became responsive to germination stimulant. Several viability tests conducted in one experiment to verify this hypothesis (data not presented) repeatedly showed that the Striga seeds were killed by the hot humid (polythene) condition. Similar effects of solar heating (solarization) were observed for many soilborne pests (Chauhan *et al.*, 1988; Horowitz *et al.*, 1983; Jacobsohn *et al.*, 1980; Katan, 1981). It appears that under such a situation, the time needed for germination induction is shortened, probably due to a rapid activation of some respiratory enzymes or mobilization of reserve foods which may be exhausted in time, thus rendering the seed non-viable (Kust, 1963; Vallance, 1951).

It was interesting to see that more Striga plants emerged in the polythene-treated plots compared to hay- and bare-soil pretreatments (Fig. 3a). Since the experiments were conducted in a striga-sick field which was under the plough for a long time, a large reservoir of Striga seed was expected to exist and incorporated in the soil profile. Because soil solarization is usually limited to <10-cm depth, where temperatures reach lethal levels (Horowitz *et al.*, 1983), most Striga seeds buried at deeper layers may escape the solarization effect. It is very possible, therefore, that the observed Striga plants in these plots could have come from depths lower than 2-cm, where conditions were not detrimental to the seeds. For example, mean maximum soil temperature at the 10-cm depth was about 10°C lower than that recorded at 2-cm soil depth and soil moisture content (another lethal factor of solarization), although not measured at this depth where the seeds were buried, was expected to be much higher than that observed at the 15-cm soil depth.

It appears, therefore, that Striga will germinate and may emerge from the host root-zone as long as (a) dormancy is broken and seeds are sufficiently preconditioned to become responsive to the host stimulant, (b) active host roots capable of producing enough exudate to induce germination are available, and (c) the growth and development of neither the host nor the parasite are interrupted during this period. In this context, therefore, Striga control practices involving treatments of top soil surfaces only, may not be effective.

Irrigation levels used as pretreatments, on the other hand, did not have any apparent effects on Striga germination and viability. Several studies showed that Striga germination was enhanced by a succession of wet and dry conditions while continuous wetting of soil suppressed incidence (Andrews, 1945; Babikar *et al.*, 1987; Ogborn, 1972). Except under the plastic mulching, where evaporation was prevented, the top 5 cm of the soil often dried up very rapidly due to the intense heat during the study period. In such a situation therefore, soil moisture changes created by the different irrigation treatments may not persist long enough to have sufficient effects on Striga seeds buried at 2-cm. It is important to note that soil moisture content (taken from the top 15 cm) are much higher, except under the polythene, than that expected at the top 2-cm where seeds were buried (Table 2).

As sorghum growth and development progressed towards maturity, more Striga plants emerged in plots previously applied with 60 mm of irrigation compared to those receiving lower rates (Fig. 3b). The cause of this increase in Striga emergence observed in these plots is not clear. Field and laboratory studies show that Striga infestation is inversely related to soil water content (Andrews, 1945). This phenomenon, however, is observed only when moisture treatments are applied during the crop growth period where wet conditions are observed to kill emerged Striga plants (Ogborn, 1972). In our study, all of the Striga plants died 30 days after emergence (Fig. 4) and none of these plants reached flowering. This was attributed to the high rainfall during the growth period (Table 1).

The application of 25–100 kg ha^{-1} of N fertilizer applied at the time of sowing significantly increased Striga emergence compared with no fertilization (Fig. 3c). However, according to

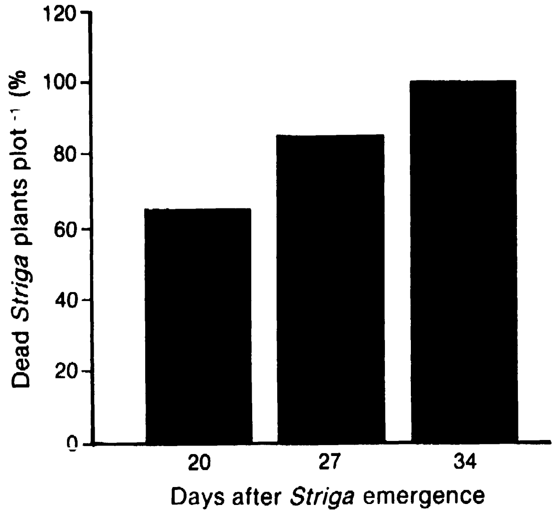

Fig. 4. Rate of Striga mortality observed in the field after the weed plants emerged.

field observations, these levels of infestations did not have any visibly adverse effects on plants receiving high rates of nitrogen. The lack of detrimental effects of Striga on crops receiving nitrogen fertilizers is in agreement with observations made by Andrews (1945), Agabawi and Younis (1965) and Williams (1961). Whether nitrogen has harmful effects on Striga is not clear at the moment. However, Solomon (1952) indicates that increased soil nitrogen levels change mass flow movements of materials to the advantage of the host plant. Although the exact mechanism involved remains unclear, our study indicates that when conditions favoring crop growth and development are improved by increasing soil nitrogen content, the harmful effects of Striga are reduced or neutralized. The increase in Striga emergence may be related to a production of more extensive sorghum root system, thus increasing the root surface areas available for parasitization which, in turn, had a more stimulating effect on the parasite.

Although the use of nitrogen fertilizers to reduce Striga infestation is yet to be demonstrated because emerged Striga plants can produce enough seeds to increase incidence, its beneficial effects on crop growth and yield increase cannot be compromised. It is important, therefore, that nitrogen applications should be combined, where possible, with other control practices (*e.g.*, chemical, hand pulling, crop rotation, *etc.*) as a long term objective of curbing Striga infestation and spread.

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