Effects of bare fallow on plant-parasitic nematodes in the Sahelian zone of Senegal[1]

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SUMMARY

Scutellonema cavenessi Sher populations declined linearly with time under bare fallow treatments in greenhouse and field studies. Final population levels in field plots in the Sahelian zone of Senegal following five months of bare fallow ranged from 0.6-3.2 % of final population levels in natural fallow plots, depending on cultivation schedule. The ability of *S. cavenessi* to survive soil desiccation (a natural, annual occurrence in the Sahel) was inversely related to the number of desiccation cycles experienced. The ability to survive soil desiccation was described by a logarithmic decay function of duration in bare fallow conditions. Metabolic or food reserves in *S. cavenessi* were estimated by a visual index of intestinal region transparency. These estimates were closely related to cultivation schedule by a straight-line log relationship ($r^2 = 0.98^{**}$) and to the ability to survive soil desiccation by a logistic model ($r^2 = 0.80^{*}$). Several other phytoparasitic nematode species exhibited trends similar to *S. cavenessi*, although their population levels under bare fallow treatments remained proportionately higher than *S. cavenessi* with respect to populations in natural fallow plots.

RÉSUMÉ

Influence de la jachère nue sur les nématodes phytoparasites de la zone sahélienne du Sénégal

Au cours d'études en serre et au champ, il a été observé que les populations de *Scutellonema cavenessi* Sher diminuent de façon linéaire avec le temps sous jachère nue. Dans les parcelles espérimentales mises en places dans la zone sahélienne du Sénégal, les niveaux finaux de population n'atteignent que 0,6 à 3,2 % des mêmes niveaux observés sous jachère naturelle, les variations étant en relation avec les types de culture. Chez *S. cavenessi*, la capacité de survivre à la dessication du sol (un événement naturel et annuel du Sahel) est inversement proportionnelle au nombre de cycles de dessication auxquels il est soumis. Cette capacité de survie à la dessication est définie, dans les conditions de la jachère nue, par une fonction de temps logarithmique décroissante. Les métabolites, ou réserves, ont été estimés chez *S. cavenessi* grâce à une échelle visuelle relative à la transparence de l'intestin. Ces estimations sont en étroite relation avec le déroulement de la culture par une relation logarithmique directe ($r^2 = 0{,}98^{**}$) et avec la capacité de survivre à la dessication par un modèle logistique ($r^2 = 0{,}80^{*}$). Plusieurs autres espèces de nématodes phytoparasites montrent des tendances semblables à celles observées chez *S. cavenessi*, bien que le taux de leurs populations dans les parcelles en jachère nue restent proportionnellement plus élevés que ceux de *S. cavenessi* si on les compare aux taux des populations sous jachère naturelle.

Long-term field experiments in the Sahelian zone of Senegal have consistently demonstrated yield losses associated with phytoparasitic nematodes in fields of peanuts, millet and sorghum, the principal crops of the region (Germani & Gautreau, 1976; Germani, 1979). Communities of plant parasitic nematodes in the region are frequently rich in numbers of species; however, *Scutellonema cavenessi* Sher, 1964 has been suggested as the major cause of nematode-related yield loss due to its ubiquitous distribution at high population levels (Germani, 1981*b*). Demonstration trials during four years showed an average 70 % yield augmentation in peanut following soil fumigation with dibromochloropropane (Baujard, Duncan & Germani, 1984). Frequent residual yield responses in successive crops of millet or sorghum may be due to the efficacy of the nematicide combined with the low reproductive rate of *S. cavenessi* at low infestation levels (Baujard *et al.*, 1985).

Despite the desirability of managing populations of plant parasitic nematodes in this region, several problems are associated with nematicide use. Soil conditions in the Sahel are suitable for fumigation only during the single rainy season between June and October. During the remainder of the year, soil moisture levels decline to < 0.3 % and nematodes exist in an anhydrobiotic condition (Demeure, 1980), so that neither soil nor nematodes are amenable to fumigation. Limited annual rainfall (150-500 mm) requires that crops be

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sown with the first precipitation of each season for maximum likelihood of obtaining a harvest. Thus, soil fumigation at planting has proven the most viable treatment strategy. Low doses of dibromo-chloropropane (DBCP) or ethylene dibromide (EDB) have been highly efficacious and are non-phytotoxic to germinating peanut seeds and emerging seedlings. However, since use of these fumigants is restricted in a number of countries, their availability will decline in the future and effective non-phytotoxic replacements were not identified in recent experiments (Baujard *et al.*, 1985). Other problems associated with nematicide use in the region are the relatively high costs of application equipment and nematicides for small-plot farmers and potential safety and health problems which may arise if nematicides are widely available to untrained personnel.

In view of potential constraints associated with nematicide use, the efficacy of alternative nematode management methods require investigation. Bare fallow is an effective nematode management practice in some systems (Rhoades, 1982; McSorley & Parrado, 1983; Sarah, Lassoudière & Guérout, 1983). In the Sahelian zone of Senegal, the practice would have the advantages of (1) low cost, since farmers possess the equipement to cultivate their soil and manpower is plentiful and (2) safety.

This paper presents results of laboratory and field experiments to determine the effects of bare fallow on the biology of several species of plant parasitic nematodes found in the Sahelian zone of Senegal.

Methods

Greenhouse studies

Prior to field tests, two experiments were conducted in a greenhouse at 26 to 29° to test the hypothesis that nematodes subjected to bare fallow conditions are less fit to survive the annual Sahelian drought period. Because the life cycle of *S. cavenessi* may include an anhydrobiotic diapause of several months duration (Germani, 1981*a*), both experiments were conducted with nematode infested soil collected at Sagata, Senegal in May 1983, following the annual dry season and prior to the first precipitation of the rainy season. The dry soil was thoroughly mixed and 250 cm^3 aliquots were measured into 10 cm diameter plastic pots. Experiments began when nematodes were revived from the anhydrobiotic condition by moistening the soil to 6 % soil moisture by weight.

The influence of repeated desiccation events on nematode population levels was measured by moistening the soil to 6 % soil moisture and allowing it to dry for seven days, at which time moisture levels were less than 0.5 %. This cycle was repeated one, two, or three times and a control treatment was maintained continuously at *ca.* 6 % soil moisture. During each seven day drying cycle, the soil was in a desiccated condition (less than 0.5 % soil moisture) for approximately two days. Thus, populations which received three desiccation events were in soil conditions moist enough to permit activity (motility) for approximately fifteen days and moistening schedules of all other treatments were adjusted so that all populations' experienced the same amount of time in an active state. At the end of their respective moisture regimes, pots in each treatment were maintained in moist condition for five days after which surviving nematodes were extracted (Seinhorst, 1962) and those passing through a modified Baermann funnel were counted. Treatments were replicated ten times.

The effect of duration of starvation on nematode survival was measured in a second experiment by maintaining populations in moistened soil without plants and extracting survivors after, 7, 14, 28, and 56 days. Interaction of starvation with ability to survive soil dessication was tested in a second series of treatments in which, seven days prior to the end of each time period, soil moisture was allowed to evaporate slowly, after which pots were remoistened for five days, and surviving nematodes extracted and counted. The eight treatments (four time periods with or without a final desiccation event) in this experiment were replicated ten times.

Field study

The influence of intensity of bare fallow cultivation schedules on nematode population levels was measured in field plots (5 × 5 m) at Nebe, Senegal in which six replications of four treatments were completely randomly assigned. Following the first precipitation of 1984 (June 14), plots were hoe-cultivated at daily (1 D), weekly (7 D), or biweekly (14 D) intervals until November 11, 1984. A natural fallow control treatment was never cultivated and 5 m wide alleys between plots were cultivated at 21-day intervals with a horse-drawn cultivator and considered as a treatment (21 D). Changes in nematode populations in each treatment were estimated *ca.* biweekly with one global sample per treatment obtained by bulking two 2.5 cm diameter soil cores (20 cm depth) from each replicate plot. Each sample was thoroughly mixed and four 250 cm^3 subsamples were obtained from each. Surviving nematodes in two subsamples were immediately extracted and counted, while soil in the remaining two subsamples were placed in 10 cm diameter plastic pots and covered with plastic lids with 2 cm holes in their centers. Soil moisture in these pots was allowed to slowly evaporate for seven days on a greenhouse bench at ambient temperature (30-33°), after which soil was remoistened for 24 h and surviving nematodes were extracted and counted. Soil moisture in each treatment was measured at each observation date after August 8. Relative food reserve content of *S. cavenessi* females and juveniles, obtained on three sample dates during August and September, was estimated by examining 100 females and juveniles from each treatment, on each date. A value of 0 to 3 was assigned to each individual based on the degree of transparency of the intestinal region. The mean proportion of individuals in each treatment that survived soil desiccation in the greenhouse was regressed against the corresponding mean treatment food reserve index value using linear and non-linear models. On November 11, each replicate of all treatments was sampled (12, 2.5 cm cores/plot) and processed as described above. Estimated final population levels were regressed against cultivation schedules using linear and non-linear models.

Results

GREENHOUSE STUDIES

Four phytoparasitic species were present in the field sil from Sagata; *S. cavenessi*, *Telotylenchus* sp., *Hoplolaimus pararobustus* (Schuurmans Stekhoven & Teunissen, 1938) Sher, 1963, and *Dolichorhynchus* sp. Mortality of all species increased with increasing numbers of dessication events and rates of decline were greater in the two ectoparasitic species, *Telotylenchus* sp. and *Dolichorhynchus* sp., than in the endoparasite *S. cavenessi* (Fig. 1). *S. cavenessi* populations subjected to three desiccation events were recovered at levels 88 % below control populations.

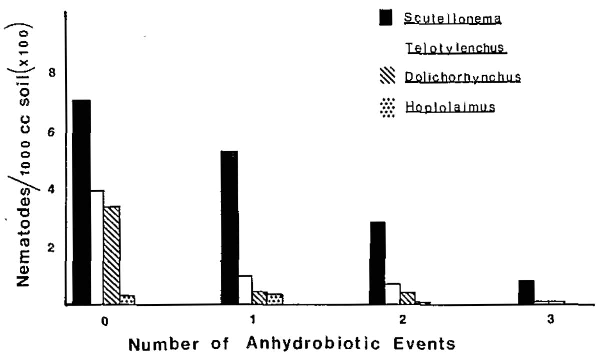

Fig. 1. Influence of number of desiccation cycles on survival of four nematode species.

In the second experiment, *S. cavenessi* populations that were maintained in moist soil without plants, declined to 76 % of their original level by day 56 (Fig. 2). A strong interaction was observed between the length of time nematodes remained in moist soil without host plants and their subsequent ability to survive soil desiccation. Eighty-nine percent of the *S. cavenessi* population survived soil desiccation after seven days in moist soil, compared to 13 % of populations which experienced 56 days in moist soil. The same interaction between length of time in moist bare soil and ability to survive soil desiccation occurred with the other three phytoparasitic species.

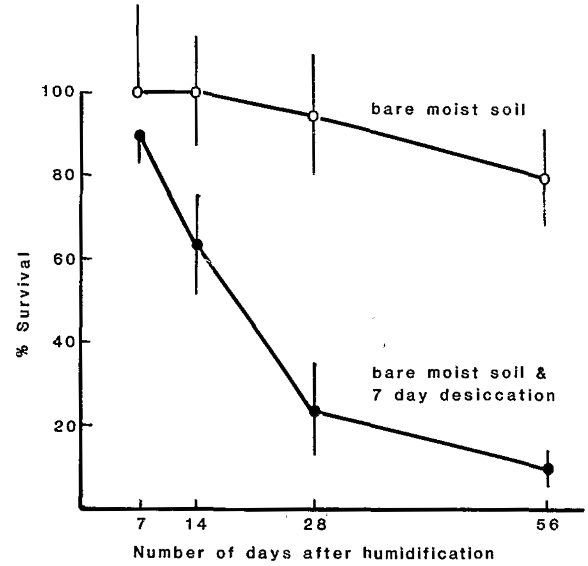

Fig. 2. Interaction between time spent in moist soil and the ability of *Scutellonema cavenessi* to survive soil desiccation.

FIELD STUDY

Results of the greenhouse experiments were confirmed in the field test. Phytoparasitic species present in sufficient quantity for analysis were *S. cavenessi*, *Dolichorhynchus* sp., *Hoplolaimus pararobustus*, *Helicotylenchus dihystera* (Cobb, 1893) Sher, 1961, and *Telotylenchus* sp. In plots which remained completely bare of vegetation, *S. cavenessi* populations declined to 66 % of original levels by day 53 (Fig. 3), similar to the 76 % level observed at the conclusion of the pot study on day 56. Effects of daily and weekly cultivation were indistinguishable when population levels were plotted against time, as were effects of cultivating each second or third week so that data from the four treatments were pooled into two groups. Linear regression of mean population levels from group 1 D + 7 D against time (Fig. 3) demonstrated relatively constant mortality during the rainy season, i.e., an increase in mortality rates over time. A similar trend occurred in group 14 + 21 D although a logarithmic decay function described the data slightly better ($r^2 = 0.96$ *vs.* $r^2 = 0.93$). Population decline was noted for all species in all treatments except the control plots containing natural vegetation (Tab. 1). *S. cavenessi* populations increased exponentially ($r^2 = 0.54^{**}$) in natural fallow plots reaching 7790 ± 2485/liter soil ($P = 0.05$). Final population levels in bare fallow treatments ranged from 0.6-3.2 % of natural fallow popula-

Table 1

Final population levels of four phytoparasitic nematode species under natural fallow and various bare fallow cultivation schedules. Standard deviations given in parentheses.

Species	Soil conditions	Natural fallow	Number of days between cultivation 21	14	7	1
Dolichorhynchus sp.	wet[a]	1950 (413)[c]	180 (123)	133 (106)	203 (141)	133 (72)
	dry[b]	1427 (612)	115 (90)	70 (81)	43 (49)	53 (45)
Helicotylenchus dihystera	wet	520 (338)	123 (132)	10 (16)	73 (99)	97 (111)
	dry	180 (188)	15 (19)	33 (81)	3 (8)	10 (16)
Hoplolaimus pararobustus	wet	623 (241)	187 (126)	113 (85)	227 (214)	210 (150)
	dry	230 (110)	75 (50)	26 (30)	26 (24)	43 (36)
Telotylenchus sp.	wet	187 (133)	20 (21)	16 (40)	0	0
	dry	97 (111)	45 (66)	33 (48)	0	0
Scutellonema cavenessi	wet	7790 (2367)	257 (195)	163 (67)	90 (49)	50 (25)
	dry	7697 (2388)	110 (11)	43 (27)	3 (8)	6 (10)

a Nematodes extracted from soil samples directly from field.
b Nematodes extracted from soil samples which were desiccated for seven days following recovery from field.
c Nematodes/liter soil.

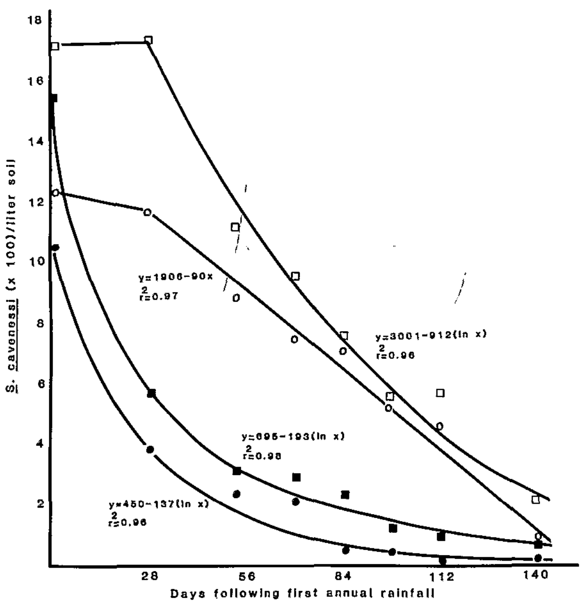

Fig. 3. Population decline of *Scutellonema cavenessi* under various bare fallow cultivation schedules. Open circle : treatments 1 D + 7 D, nematodes extracted from moist soil; closed circle : treatments 1 D + 7 D, sample desiccated for seven days prior to extraction; open square : treatments 14 D + 21 D, nematodes extracted from moist soil; closed square : treatments 14 D + 21 D, sample desiccated for seven days prior to extraction.

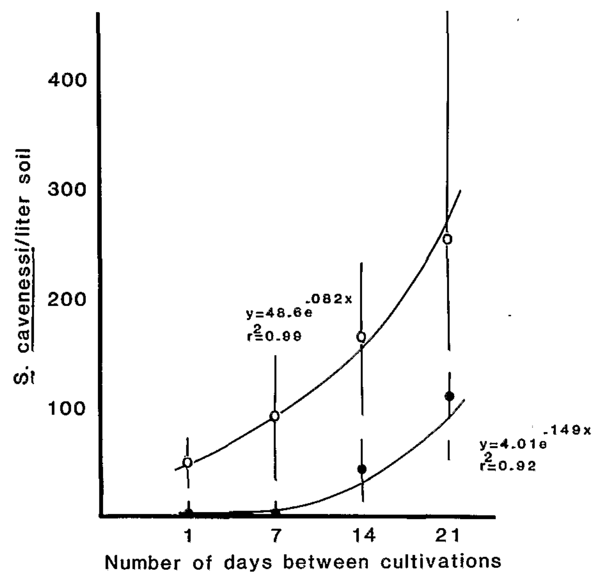

Fig. 4. Final *Scutellonema cavenessi* population levels under various bare fallow cultivation schedules. Open circle : nematodes extracted from moist soil; closed circle : soil desiccated for seven days prior to extraction.

tion levels and were exponentially related to the cultivation schedule (Fig. 4).

When nematodes were subjected to gradual soil desiccation, in the greenhouse, population levels of cultivation treatments declined in a negative exponential manner over time (Fig. 3). Linear regression of the proportions of treatment final populations which survived soil desiccation against cultivation schedule suggests that this ability is related to the amount of time during which plant roots are present in the environnement (Fig. 5). Similarly, relative food reserve content was a good predictor ($r^2 = 0.80$) of the ability of populations to survive soil desiccation when described by a logistic model (Fig. 6). Relative food reserve index was closely related to cultivation schedule (Fig. 7).

Soil moisture levels were consistently higher in cultivated treatments than in the uncultivated control (Fig. 8).

Discussion

The efficacy of bare fallow as a cultural nematode management practice is related to climatic and edaphic conditions and to the particular biologies of the local nematode species. Since the Sahelian region in Senegal is characterized by a strict, unimodal rainfall distribution, three, distinct periods may be encountered by nematodes subjected to bare fallow : (1) a rainy season during which humid soils contain no host root systems, (2) a dry season when low soil moisture levels are obtained, and (3) a second rainy season when host roots are permitted to grow. The present experiments suggest some responses by several nematode species to each of these periods.

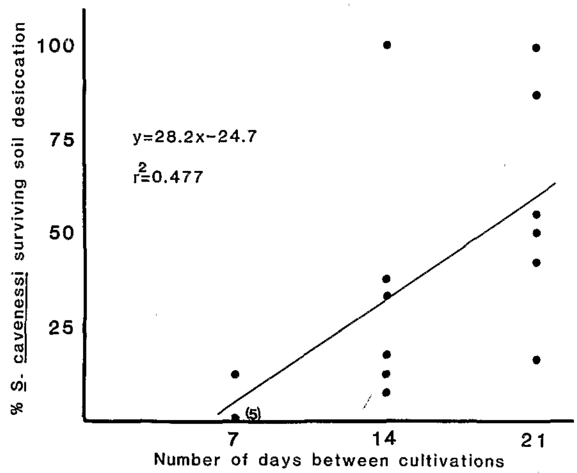

Fig. 5. Effect of bare fallow cultivation schedules during a period of 150 days on the ability of *Scutellonema cavenessi* to survive soil desiccation. Samples collected 150 days following initial seasonal rainfall and dried for seven days prior to nematode extraction.

During the course of the first growing season, *S. cavenessi* populations declined to very low levels under all bare fallow cultivation regimes (Fig. 3). The highest final population level (257/dm³ soil) which was measured in treatment 21 D was equivalent to population levels in adjacent

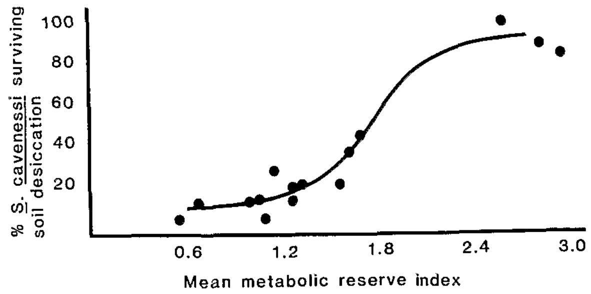

Fig. 6. Relationship between mean food-reserve index (n = 100 females and juveniles) and ability to survive soil desiccation.

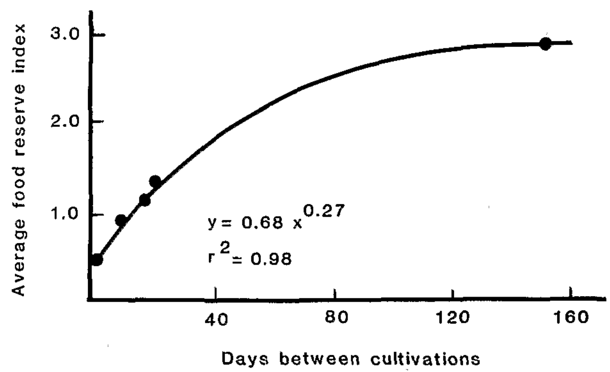

Fig. 7. Relationship between mean food-reserve index (n = 300 females and juveniles) of *Scutellonema cavenessi* and bare fallow cultivation schedule.

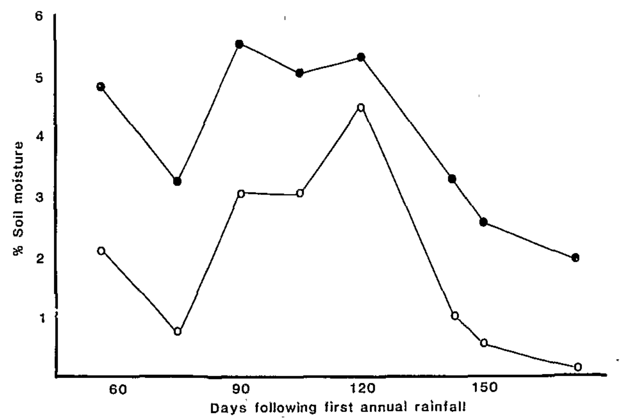

Fig. 8. Average soil moisture levels in bare fallow (closed circle) and natural fallow (open circle) plots.

experimental plots following treatment with recommended rates of DBCP (Baujard *et al.*, 1985). Thus, although final *S. cavenessi* population levels were exponentially related to cultivation schedules (Fig. 4), it may be possible to obtain good management of this species with very few cultivations during the growing season.

Bare fallow treatments were not as effective in reducing population levels of other nematode species (Tab. 1). Trends relating cultivation schedules to survivorship were not generally evident, possibly because lower initial population levels and patchier distributions resulted in more variable population estimates. Final population levels of *Telotylenchus* sp. and *Dolichorhynchus* sp. were less than 7 % of the normal fallow population levels, whereas *Helicotylenchus dihystera* and *Hoplolaimus pararobustus* levels were only reduced by an average of 85 and 70 %, respectively. Nevertheless, population levels should continue to decline during the six months prior to the succeeding rainy season and it is unknown whether these species are pathogenic to regional crops. Further, with the exception of *S. cavenessi*, peanut is a poor or non-host to all species in the present experiment (Baujard *et al.*, 1985), so that following a season of bare fallow with a peanut crop (a traditional rotation when normal fallow is employed) may further reduce the levels of many species.

The ability of *S. cavenessi* to survive soil desiccation declined in relation to time spent in moist bare soil in both the greenhouse and the field (Figs. 2, 3). Results in the greenhouse test of survival as a function of the number of drying cycles (Fig. 1) confirm previous results with other species which suggest that entry into and recovery from an anhydrobiotic state requires considerable energy expenditure (Womersley, 1980; Storey, Glazer & Orion, 1982; Glazer & Orion, 1983). The close relationship between the mean population food reserve index and the ability to survive soil desiccation supports this view. Nevertheless, further information is required to predict how the various treatment populations will survive the dry season. Final measurement of population ability to survive soil desiccation occurred in November when soil moisture levels were quite high in bare fallow plots. It is not clear whether in the absence of plant transpiration, soils will dry sufficiently to induce an anhydrobiotic condition in nematodes (Fig. 8). Conversely, considering mortality rates during the course of the rainy season, continuously moist soil conditions during both rainy and dry seasons may provide the highest level of control.

The biotic potential of nematodes which survive the stress of bare fallow conditions during the course of a wet and dry season in the Sahel is unknown. Nevertheless, positive correlations between food reserve content and motility or host infectivity are well documented (Van Gundy, Bird & Wallace, 1967; Reversat, 1980) and suggest that nematodes surviving a bare fallow season may be incapable of performing functions necessary to complete the life cycle when host roots are reintroduced to the soil.

The results presented herein support the use of bare fallow as a means of nematode management in the Sahelian zone of Senegal. Incorporated into the cereal-legume-fallow rotation schedules currently practiced, a single bare fallow season may result in long-term control of *S. cavenessi* due to an underpopulation effect in low infestations of this amphimictic species which may seriously retard its reestablishment (Duncan, unpubl.). Soil ~~erosion~~, a common drawback to bare fallow use, is unlikely to effect soils in this region where wind erosion is a natural condition during the six dry months of each year. The main restriction to the amount of land that could be bare fallowed annually in a given locality is the need of natural fallow fields for livestock forage.

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