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Epidemiology of Sorghum Downy Mildew. V. Incidence of Systemic Infection

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Incidence of sorghum downy mildew systemic infection was observed at a growth stages of sorghum plant in the 8 crops and 64 weekly sowings. Nine types of systemic symptoms arising from host parasite interactions were recognized. Production of infected nodal tillers and ratoon tillers was noticed in plants which were free from systemic symptoms, even upto ripening stages.

Sorghum plant as a whole was susceptible to systemic invasion untill 21 days after sowing and symptoms were expressed at different growth stages. For accurate determination of systemic infection, plants of 3 scores, viz., 15, 55 and 90 days old after emergence, are suggested.

Early systemics mainly produced conidial inoculum and a majority of them were killed. Late systemic mainly produced oosporic inoculum and majority of them lived until maturity of the crop. A great variation in the incidence of systemic infection was noticed between weekly sowings as well as kharif and rabi crops, maximum incidence being noticed in sowings made in November. While oosporic inoculum was responsible for primary infections only in a small percentage of plants, airborne conidia were found to be mainly responsible for the development of systemic infections in epiphytotic proportions causing immense loss in grain and fodder.

Key Words: Epidemiology, Sorghum downy mildew, Systemic infection

Introduction

Sorghum downy mildew (SDM) caused by *Peronosclerospora sorghi* (Weston & Uppal) Shaw is now recognized as an important pathogen of both sorghum and corn crops. While the local lesion infection is relatively less harmful (Cohen & Sherman 1976 Rajasab et al. 1979 b), the systemic infection (SI) is responsible for losses in both sorghum and corn crops (Frederiksen et al. 1973, Cohen & Sherman 1976). SI in the case of sorghum is initiated by oospores in soil or those associated with seeds or

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through conidial infections invading meristem of young plants. SI caused by oospores in soil was shown earlier in India by Weston and Uppal (1932) and details of infection history were studied by Suryanarayana (1954). In our previous reports the disease scales for local lesion infection (Shenoi & Ramalingam 1976), the aerial dissemination of conidia and oospores (Shenoi & Ramalingam 1979, Rajasab et al. 1979 a) and incidence of local lesion infection (Rajasab et al. 1979 b) were presented. The latter two papers in addition to the description of aerial dissemination of conidia, also presented data on the aerial dissemination of oospores and their role in the contamination of soils as in the case of downy mildew of pearl millet (Suryanarayana 1965). Thiscommunication deals with the incidence of SI in crops and weekly sowings as well as in artificial inoculations using conidia.

Materials and Methods

A local variety of sorghum 'Bili jola' was used throughout our studies. Field observations were made on crops and rows at 5-day or weekly intervals as reported earlier (Rajasab et al. 1979 b). In weekly sowings made between 5 April 1977 and June 1978, each plant expressing SI was tagged with an aluminium foil bearing a number. A total of 969 plants were tagged and data were collected on growth stage of plant, expression of disease, type of symptom, conidial or oospore production, death and so on.

For experimental work, sorghum plants were raised in sterilized earthen pots and were inoculated with conidial suspensions into whorls with the help of pipette, when they were 1 to 21 days old after emergence. The plants were kept in a moist pit in the ground, at high humidity, for 8 hr and then transferred to a shady place free from conidial inoculum. Controls were maintained. SDM infection was recorded on the 26 day after inoculation.

Results

Expression of systemic infection

Systemic infection was expressed in plants right through all the growth stages of the plant and even after harvest on ratoon tillers. Systemic infection appears as mottled spots, when seen against light, often in longitudinal streaks, but always extending from the base of leaf towards the apex, sometimes giving rise to 'half leaf symptoms'. Extending type local lesions formed on young plants (Rajasab et al. 1979b) may be confused for SI symptoms, but they always extend from tip to the base of leaf and with experience they could be easily distinguished. They lack mottled appearance and sporulate quickly. Two types of systemic infection symptoms are noticeable: (1) conidial symptoms with downy growth and (2) oospore symptoms with fast decolourization, tan to brown, leaf thinner and smooth in colonized areas, often heavily infected by saprophytic fungi and show back patches. The leaves bearing oospore stages shred longitudinally and drop oospores into air. Plants expressing systemic symptoms in the late vegetative stages often show hooked leaf at tip, or crooking due to the difficulties in emergence from the whorl. In some cases all leaves may be free from infection and systemic symptoms may appear only on boot and inflorescence. On the basis of our long term observations (1971 to date) the following 9 types of host parasitic interaction were recognized:

I. Early systemic (before 6-leaf stage) with asexual stages only

II. Early systemic with dominant asexual and scanty sexual stages

III. Early systemic with dominant sexual and scanty asexual stages

IV. Late systemic with only asexual stages

V. Late systemic with dominant asexual and scanty sexual stages

VI. Late systemic with dominant sexual and scanty asexual stages

VII. Systemic infection only affecting inflorescence and all leaves free from any symptoms

VIII. Leaves of nodal tillers expressing systemic infection

IX. Basal tillers arising from infected as well as healthy plants expressing systemic symptoms

The data on the expression of systemic infection, up to flag-leaf stage, recorded in 969 tagged plants, collected from weekly sowings are presented in figure 1. Disease expression was observed at all growth stages, maximum at 4-leaf stage. Majority of the plants expressing disease before 6-leaf stage, produced only conidial stages and sexual stages were produced in abundance in the growth stages that followed.

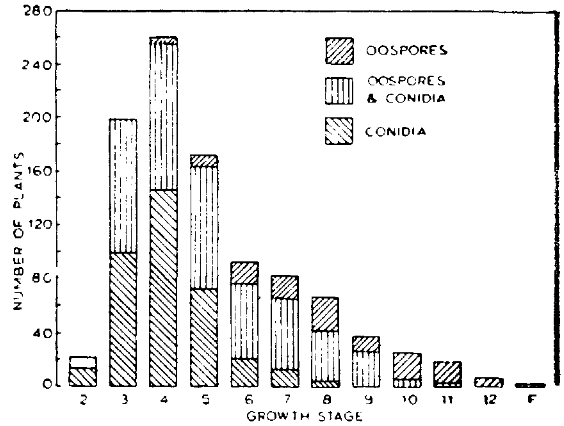

Figure 1 Expression of systemic symptoms of sorghum downy mildew at each growth stage and relative preponderance of conidial and oospore stages in weekly sowings

We were late in recognizing SI of type VII, VIII and IX stated above, and data on their incidence was collected only in the weekly sowings made in 1979. It was found that 2.4% of the plants in flowering stages exhibited type VII infection, 4.3% of the plants in seed ripening stages produced infected nodal tillers and 2.7% of the ratoon tillers arising from the healthy plants exhibited SI symptoms.

Table 1 *Incidence of infected nodal tillers on systemically infected plants as well as healthy plants in the Rabi crop of sorghum, 1978*

Field row counted	No. of plants observed	No. of systemically infected plants		No. of apparenty healthy plants		
		without nodal tillers	with nodal tillers	with infected tillers	with healthy tillers	without tillers
1	294	47	30	1	15	201
2	227	40	27	4	11	145
3	215	31	20	5	17	142
4	186	27	33	0	5	121
Total	922	145	110	10	48	609
% of tillers		43			7	

An interesting observation was the occurrence of infected nodal tillers on plants which have not shown any symptoms on leaves or inflorescences. In the rabi crop of 1978, raised in our experimental field, 1.1% of apparently healthy sorghum plants which were in maturing stages were found to be bearing infected nodal tillers. Further, the incidence of nodal tillers was 6 times greater in infected plants than in the healthy plants (table 1). Such excessive tillering was noted in the case of pearl millet downy mildew by Suryanarayana (1965). In a few plants, it was also observed that some plants bore infected tillers at the top nodes while the nodal tillers at the lower nodes on the same plant were free from infection.

Incidence of systemic infection in eight Crops

The number of living plants bearing SI showed a continuous increase from 2-leaf stage, reached a peak at Flag-leaf stage and declined thereafter to a low figure by the time of harvest (figure 2). A variation from this pattern was observed in some crops. In the rabi crop of 1971, about 1.5% plants expressed SI symptoms at 5-leaf stage, but instead of showing an usual increase in number they declined to a very low count by the 12-leaf stage itself. This crop was very weak due to decreased fertility and failure of rains. In kharif crops of 1971 and 1978, instead of a continuous decline in the count of systemics after the flag-leaf stage, a second but shorter peak was noticed at soft dough stage, due to expression of infection in nodal tillers.

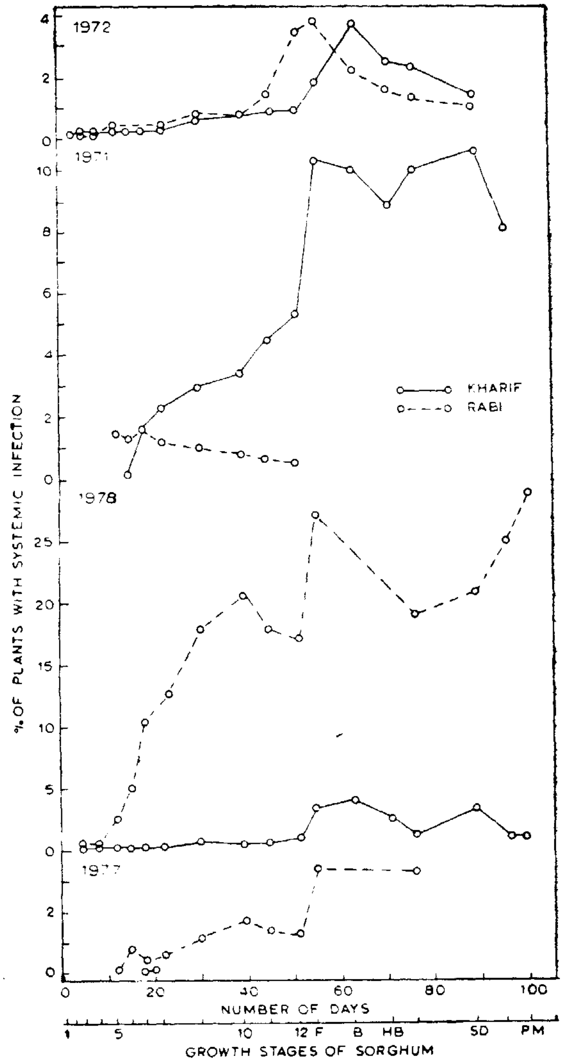

Figure 2 Sorghum downy mildew systemic infection in 8 crops. Data represent the systemics counted at each growth stage

Seasonal incidence of systemic infection in weekly sowings

The percentage of SI presented in figure 3 are averages of weekly showings made in each month. The data scored for each sowing is the cumulative total of all systemics (dead and living) which expressed infection from emergence to harvest. The percentage of infection varied from sowing to sowing. However, a marked seasonal pattern could be seen which seems to be influenced by temperature and leaf surface wetness. The maximum incidence of 40 to 96% was observed during October–February period

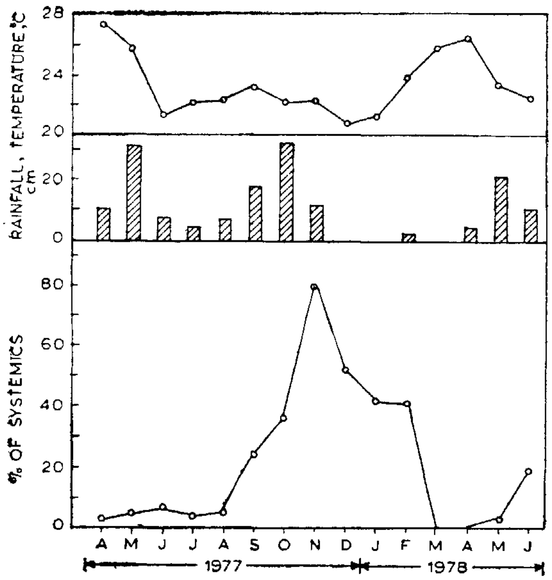

Figure 3 Incidence of sorghum downy mildew systemic infection in 68 weekly sowings related to weather. Data are monthly means

when the average atmospheric temperature of the day, particularly of the early forenoon hours, was below 22°C and the leaves were wet for 4–8 hr with dew deposits or condensation water. The plants received conidial inoculum from the neighbouring rows. The high incidence of SI in December and January sowing when there was no rainfall, indicates that rainfall did not influence the disease incidence directly, but may do so by reducing temperature and increasing condensation on the leaf surfaces. In November, in addition to the existence of optimum temperatures and dew deposition in the forenoon hours, rainfall is also received from Northeast monsoon and thus provided most suitable weather for the development of SDM. Rabi crops, if sown in this month, are likely to suffer very heavily from SDM at Mysore.

Death of systemically infected plants

Premature drying followed by death was noticed in systemically infected plants from 5-leaf stage until harvest. Such premature drying was also noted by Suryanarayana (1965)

Table 2 *Data showing the relationship between sorghum downy mildew systemic infection expressing at various growth stages and the death of them at various crop growth stages*

Growth phase	No.*	Growth Stages												Total dead	%
		E-3	4	5	6	7	8	9	10	11	12	F	B-PM		
2	21	0	0	5	3	2	3	0	0	0	1	0	0	14	66.7
3	201	0	12	11	16	15	12	4	3	3	2	1	1	80	39.8
4	258	0	0	24	27	20	17	15	8	6	5	0	0	122	47.3
5	171	0	0	0	12	18	10	—	12	—	4	1	0	57	33.3
6	92	0	0	0	0	1	1	2	1	4	1	0	0	10	10.9
7	82	0	0	0	0	0	0	2	2	1	0	0	0	5	6.1
8-PM	144	0	0	0	0	0	0	0	0	0	0	0	0	0	0.0
Total	969	0	12	40	58	56	43	23	26	14	13	2	1	288	29.7

* No. of plants expressing systemic infection
— Data not recorded,
E-3: Emergence to 3-leaf stage, B-PM: Boot-leaf to physiological maturity

in pearl millet attacked by downy mildew systemically. In some such plants tillers were produced at base and invariably bore systemics symptoms. The number of plants

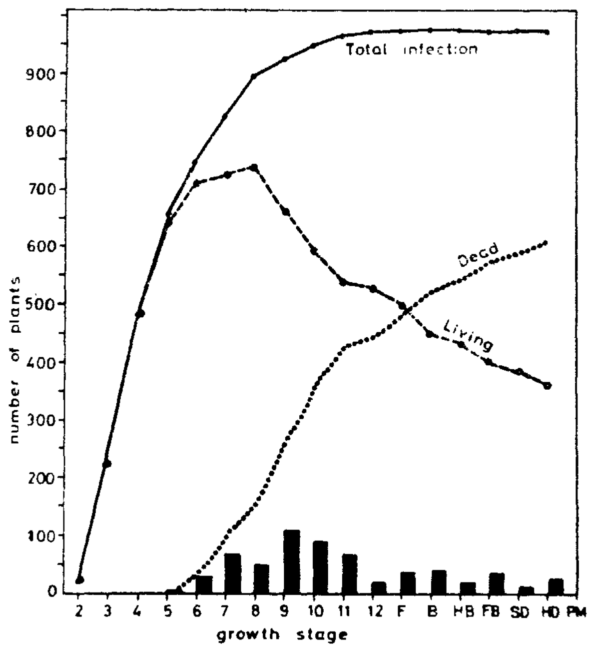

Figure 4 Data on the fate of 969 tagged systemically infected plants. Curves are cummulative totals of plants expressing infection, death and living. Histograms represent the number of plants killed at each growth stage

succumbing to infection was highest at 6-leaf stage and declined thereafter (figure 4). In weekly sowings 29.7% of the systemics were killed before harvest.

The data given in table 2, bring out the relationship between the disease expression at various growth stages and their death at various growth stages. Plants which expressed disease symptoms before 7-leaf stage only succumbed to infection and none which expressed systemic infection in the growth stages that followed. Maximum percentage of death was observed in plants that expressed disease at 2-leaf stage and the percentage death declined when the expression was in later stages following it. Further, when the expression is late the death of plants if any, was also postponed to later growth stages.

Susceptibility of plants to systemic infection

In sorghum plants inoculated with conidial suspension into whorls, the disease symptoms appeared on unfolding leaves on the 8 day after inoculation. The percentage of infection was found to be highest in the plants that received inoculum at emergence (figure 5) and the incidence

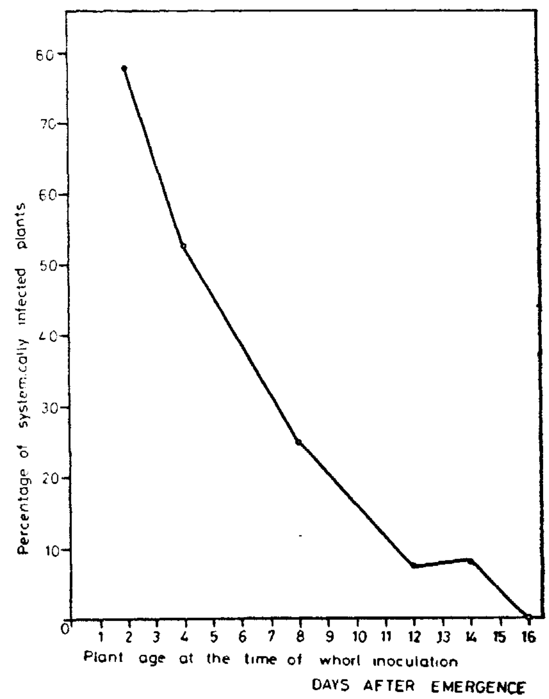

Figure 5 Incidence of systemic infection on sorghum plants inoculated with conidial suspension into whorls at different ages

decreased with increasing age. None of the plants that are 16 days or older than that after emergence, at the time of inoculation, expressed systemic symptoms on 26 day when the last score was taken.

In weekly sowings we had the opportunity of observing a completely disease free period, usually in the dry months of March and April, which was followed by the appearance of disease in rows and its spread, after a heavy summer shower or monsoon rains. The data for three such periods, summers of 1977, 1978 and 1979, are presented in table 3. In May 1977 the source was a single systemic in row 3, probably arising from oospore infection; in May 1978 it was conidia coming from an external source by air and in March 1979, it was a single systemic arising from oosporic infection in row 5 (data given for the latter by Rajasab et al. 1979b). The data reveal that whether the infection is oosporic or conidial in origin, the subsequent increase in the number of systemically infected plants depends on the spread of conidial inoculum from these primary sources and reaches epidemic levels when it falls on very young plants and decreases with the increase in the age of the plants.

Table 3 *Incidence of systemic infection in weekly sowing of three chosen periods, following a dry downy mildew free season, arising from the deposition of air-borne conidia of* Peronosclerospora sorghi *on young plants*

Growth stage	% of systemic infection in each period			Mean %
	1977	1978	1979	
Emergence	—			29.8*
3-leaf	6	7	13	8.7
4-leaf	—	2	—	2.0
5-leaf	3	—	3	3.0
6-leaf	—	—	4	4.0
7-leaf to Flag-leaf stage	0	0	0	0.0

* Average of 45 sowings exposed to air-borne conidial inoculum coming from infected plants in the neighbouring rows

Discussion

Sorghum plants expressed SI in different stages of growth, right from 2–leaf stage until the harvest, and later even on ratoon tillers. These infections might originate from oospore infections or from conidial infections. Shetty et al. (1979) using oospores for inoculation of sorghum plants (DMS 652) through soil observed systemic infection at different growth stages on 36 of the 1,650 plants, each of which was raised in isolation. In our studies reported in this communication (figure 4) as well as those presented elsewhere (Ramalingam & Rajasab 1980) we have observed that the plants inoculated with conidial suspensions also expressed SI at various growth stages. The declining count of systemics with increasing age of the plants again showed an increased expression at flag-leaf, flowering and grain-maturing stages. This may be attributed to the expression of latent infections of *P. sorghi* or SI caused by their air-borne conidia on emerging inflorescences and nodal tillers.

While Frederiksen et al. (1973) recognize four types of host parasitic interactions, we could recognize nine types. While the first three types seedling systemics, majority of which are conidial producers; the next four types could be called as late systemics which predominantly produce oospores. While a great majority of early systemics are killed by SDM infection, majority of the late systemics lived until the crop was harvested exhibiting the characteristic leaf shredding, sickle leaf, inflorescence and nodal tiller infection symptoms. Frederiksen et al. (1973) and Kenneth and Shahor (1975) have also observed death of SDM infected plants, but no quantitative data was presented in their reports. Since 30% of the systemically infected plants were killed at various growth stages, diseases scores taken at any growth stage are only under estimates of total infection, as many of these plants are not available for counting, as was also stated earlier by Suryanarayana (1965) in the case of SI by downy mildew of pearl millet. Even with this limitation the best stage for scoring SI seem to be flag-leaf stage. If an accurate count is aimed, two more scores, one at 6-leaf stage and another at soft dough stage, could be taken. These stages would correspond approximately to 15, 55 and 90 days after emergence.

As recorded in the previous studies (Cohen & Sherman 1976, Jones 1978, Rajasab et al. 1979) the SDM infection was pronounced on the eighth day after inoculation, both under field and artificial conditions. Probably this is the minimum time required for the expression of systemic symptoms from the time of entry of the pathogen. Sorghum plants are susceptible to SDM SIs up to 16 days after emergence a total of 21 days from sowing. Cohen and Sherman (1976) attribute SI to the extension of local lesions from young leaves to meristem. Jones (1978) attributes it to the penetration of stem at soil surface. Our study reveals that conidia falling into the whorl could also develop SI. Thus it could be concluded that the meristem as well as any tissue of the sorghum plant which is young is susceptible to SDM SI. Our observations on the occurrence of nodal and ratoon tillers, even on healthy plants, show that these infections, at least partly, have arisen from the infection of meristem of tillers from air-borne conidia of *P. sorghi*. In tissues older than 21 days the host-parasite interaction leads only to the development of local lesions. As the organs and tissues become further aged they become resistant even to the conidial infections. Vanderlip & Reeves (1972) showed that the differentiation of meristem to leaves and inflorescence is completed by 30 day after emergence. It appears, the meristem in sorghum plants is apical in position to begin with, cuts off cells towards the lower surface which develop into leaves and at a certain stage (probably 16 days after emergence) it begins to cut off cells towards the upper side also, which produce the inflorescence. Thus the meristem becomes intercalary in position. In addition to the tightly packed leaves, the mature tissues of the inflorescence apex obstructs the conidial inoculum falling into the whorl from contact with meristem and this is probably responsible for the reduction in infectivity of meristems, which is a prerequisite for SI. Cohen & Sherman (1976) injected conidia to the stems of plants past 6-leaf stage and obtained SI successfully.

Seedlings develop SI either from contact of roots with soil-borne oospores or aerial parts with air-borne conidia. Suryanarayana (1954) stated if germinable oospores come into contact with underground parts, SI of seedling sreadily takes place. Safeeulla and Thirumalachar (1955) and Safeeulla (1976) have induced SI on seedlings through contact of conidia with roots of seedlings. In our experiments as well those of Jones (1978), Cohen and Sherman (1976), SI was readily produced by conidia used as spray or through leaf contact, or whorl inoculation or spore fall methods. These young systemics predominantly produced conidia and a majority of them were killed (figure 6). Further spread of disease seems to be dependent only on conidial inoculum coming from living systemics, local lesions, conidia bearing late systemics, nodal and ratoon tillers. while the conidia falling on

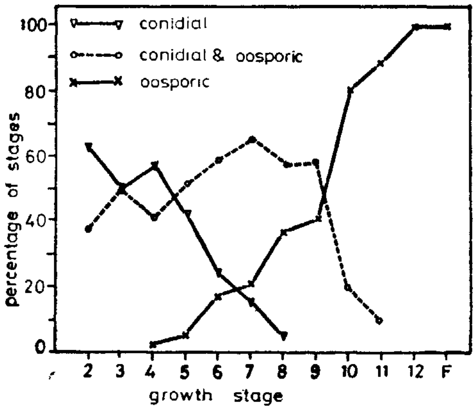

Figure 6 Percentage of infected plant leaf area occupied by eonidial and oosporic stages of sorghum downy mildew at each growth stage of sorghum plants

leaves and in whorls of young plants develop SI those falling on mature leaves develop local lesions. The different types of late systemics reported here, a majority if not all, probably result from conidial infection of young meristematic tissues. These late systemics predominantly produced oospores in leaves, dropped them to ground by shredding of the leaves and thus build up soil-borne inoculum for the next crop. Majority of the systemics which received SI from oospores produced conidial stages and were dead prematurely. Only a small number lived longer and produced oospores. Where the symptoms appear only on inflorescence (seed, glumes and so on) the infection may be carried through seed as stated by Sofeeulla (1976) and Jones (1978). The infection of nodal tillers is probably by air-borne conidia falling into their whorls. Similarly the infection of tassels and cobs in maize and the conversion of them into characteristic phyllody symptoms, a majority if not all, is also probably brought by air-borne conidial infections of the inflorescence meristems. The nodal tillers as well as ratoon tillers, in addition to the local lesions, play an important role in extending the period of conidial inoculum froms tanding crop and act as foci for late sowings or crops of the next season.

Cohen and Sherman (1976) have recorded a proportionate loss in sweet corn with percentage of SI observed in the crop. Frederiksen et al. (1973) report loss in grain, fodder and seed quality in sorghum due to SDM infections. Apart from these, death of systemically infected young plants will also cause increased losses by way of loss of costly seed as in hybrids, thin stands and wastage of fertilizer and land due to the thinning of the crop.

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