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Disease management factors influencing yield and quality of sorghum and groundnut crop residues

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Abstract

Crop residues from groundnut and sorghum constitute important fodder resources for dairy production and fodder trading on the Deccan Plateau in India. This paper addresses the effect of important diseases of groundnut and sorghum on pod and grain yield and crop residue yield and quality. In four genotypes of groundnut, late leaf spot (*Phaeoisasariopsis personata*) and rust (*Puccinia arachidis*) are the two major foliar diseases that together could reduce pod and haulm yield by 70% and in vitro digestibility of haulms by 22%. Two genotypes (ICGV 9202 and 92093) were highly resistant to these foliar diseases maintaining high pod and haulm yield as well as high in vitro digestibility of haulms (>62.3%) even under highest disease pressure. Important diseases in sorghum investigated were a viral disease caused by maize stripe virus (MStV) and anthracnose caused by *Colletotrichum graminicola*. MStV reduced grain yield by 30%, stover yield by 42% and digestible stover yield by 45%. Effects of MStV were highly genotype-dependent and grain and stover were affected in different ways in different varieties. The choice of appropriate genotype for a given farming situation will depend on trade-off scenarios for benefits from grain and stover. Similarly, anthracnose could reduce grain yield by 47% and stover yield by 23% but effects on stover quality were variable. As observed for MStV, effects of anthracnose were highly genotype-dependent and genotypes were identified that maintained high grain and stover yield under high disease pressure.

Keywords: Disease management; Sorghum; Groundnut; Crop residues; Yield loss; Nutritional quality

1. Introduction

Crop residues of groundnut (*Arachis hypogaea* L.) and sorghum (*Sorghum bicolor* (L.) Moench) provide important feed resources in the semi-arid tropics (SAT) of India and Africa (Zerbini and Thomas, 1999). While the effects of plant diseases on grain and pod yields have been investigated for some time, little is known about the effects of plant diseases on fodder value of sorghum stover and groundnut haulms.

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On the Deccan Plateau of India, the study area of this work, locally grown cultivars of groundnut are susceptible to late leaf spot (LLS), caused by *Phaeoisasariopsis personata* and to rust, caused by *Puccinia arachidis* (Pande et al., 2001). These two foliar diseases prematurely defoliate plants, leading to losses in pod and haulm yield. As summarised from field survey reports (Navi et al., 2001), anthracnose, caused by *Colletotrichum graminicola*, and maize stripe viral disease (MStV), caused by a tenuivirus, are prevalent diseases of sorghum in most parts of India (Indira et al., 2002; Narayana et al., 2002). Anthracnose can attack all plant parts. Premature destruction of leaf area and infection of developing grains result in considerable reduction in stover and grain yield (Thomas et al., 1996). MStV systemically infects plants causing stunting. Depending on the growth stage at which infection occurs, infected plants either do not produce panicles or set few seeds if panicles are produced (Narayana et al., 2002). The virus is persistently transmitted by the plant hopper *Peregrinus maidis*, which is also a key pest of sorghum (Narayana et al., 2002).

Participatory rural appraisal studies by Rama Devi et al. (2000) have shown that sales of crop residues to peri-urban milk-producers accounted for approximately 50% of the income from cropping in rural areas of the Deccan plateau. Since diseased fodder commands lower prices in the fodder markets, plant diseases exert a direct negative impact on livelihoods by reducing grain and pods yields and, additionally, crop residue value (Rama Devi et al., 2000). On the other hand, Kristjianson and Zerbini (1999) determined that an increase in quantity and quality of stover and haulms will directly improve livelihoods in mixed crop–livestock systems.

In spite of the significance of crop residues to farm income, only sparse data are available on the effect of plant diseases on yield and quality of sorghum stover and groundnut haulms (Pande et al., 2001). Genotype-related resistance to deterioration in crop residue quantity and quality has until very recently not been explored (Bandyopadhyay et al., 2001). The present study investigated the effects of foliar diseases (LLS and rust) on pod yield and haulm yield and quality in four genotypes of groundnut subjected to varying degrees of disease pressure. In sorghum, the effect of MStV and anthracnose diseases on grain yield and stover yield and quality was investigated for three and five genotypes, respectively.

2. Materials and methods

2.1. Experimental site

The experiments were conducted from the 1999 to 2000 seasons on Alfisol (groundnut) and Vertisol (sorghum) soils at the experimental farm of the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT), Patancheru, Andhra Pradesh, India (17°10′N and 78°28′E and 543 m above mean sea level). The weather data (maximum and minimum temperatures, relative humidity and rainfall) were collected from a meteorological station, 200 m away from the experimental plots and are summarised in Fig. 1.

2.2. Groundnut

2.2.1. Genotypes and experimental design

Four genotypes of groundnut, ICGV 91114 (early-maturing, matures in 95 days), ICGV 92020, 92093 (medium-maturing, matures in 125 days) and TMV 2 (similar to farmer's local cultivar, matures in 110 days) were used in this experiment. The experiment was sown in the last week of June 2000 (rainy season) in a split-plot design with disease management practices (treatments) as main plots and genotypes as sub-plots with three replications. Each plot consisted of four rows of 9 m length with 60 and 10 cm of inter- and intra-row spacing, respectively. One infector row of the susceptible cultivar TMV 2 was planted after every four test rows to ensure uniform and high disease pressure throughout the experimental plots. At 35 days after sowing (DAS) diseased crop debris, collected from the previous cropping season, was evenly spread around the infector rows. Additionally, the infector rows were sprayed with a suspension of conidia of *P. personata* and urediniospores of *P. arachidis* during the evening of a cloudy day. Sprinkler irrigation was provided every evening for 30 min to maintain leaf wetness at night. The treatments consisted of intensive management (IM—least disease), moderate management (MM—moderate disease) and no management (NM—most disease) to control both LLS and rust to desirable levels. In the IM practice, the fungicide

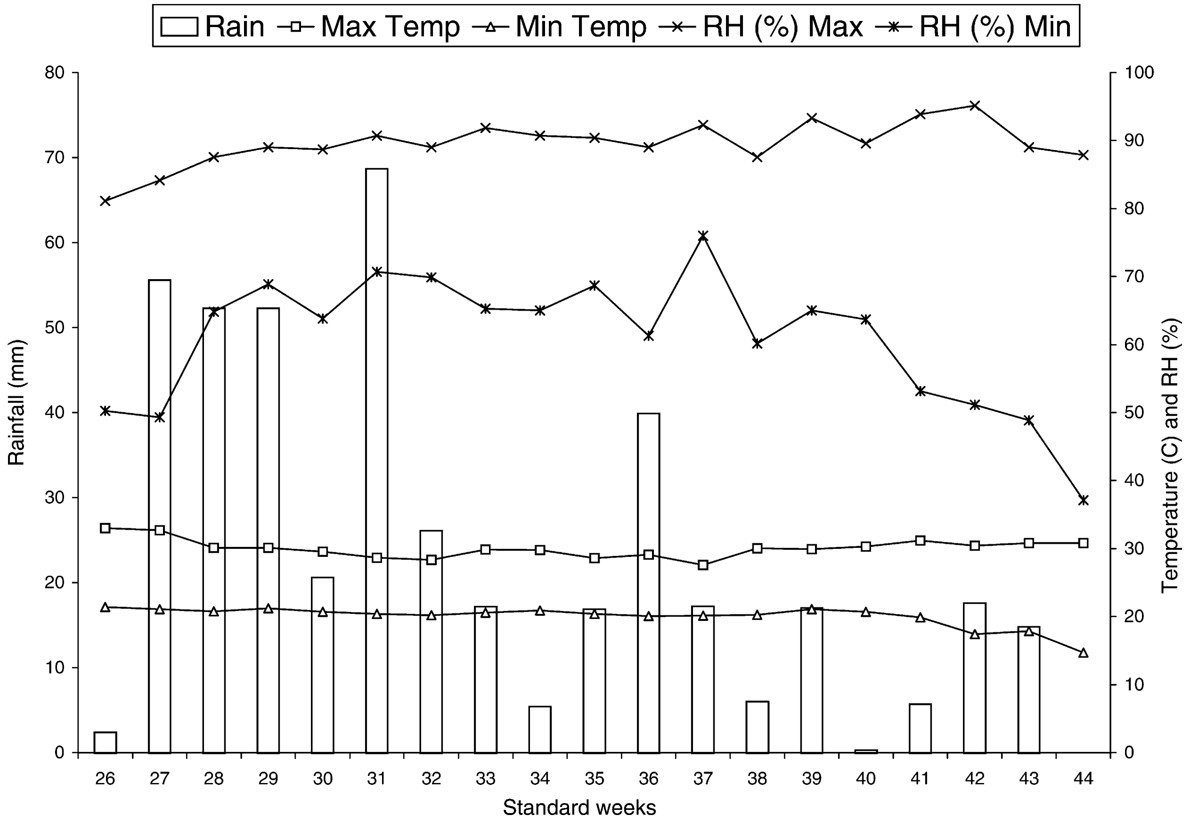

Fig. 1. Summary of weather data at Patancheru during the groundnut field experiment in 2000.

Kavach® (chlorothalonil) was applied as a foliar spray at 10-day intervals from 30 DAS till maturity. In the MM practice, Kavach was applied as a foliar spray at 60, 75 and 90 DAS. In the NM practice, the fungicide was not applied throughout the crop season.

2.2.2. Data collection and sampling for haulm quality assessments

Severity of foliar diseases (both LLS and rust) was scored at 10-day intervals from 45 DAS till maturity on a modified 1–9 rating scale where 1: no disease and 9: maximum disease, i.e., almost complete defoliation (Subrahmanyam et al., 1995). At maturity, all plots were harvested by uprooting all plants. Pods were handpicked and both pods and haulm were sun-dried. After complete drying, haulm and pod weights were recorded to calculate yield per hectare.

For haulm quality analysis at maturity, about 20 plants from each plot were cut at the collar region. After harvesting and hand picking of pods, haulms were oven dried at 50 °C until they attained a constant weight, and ground less than or equal to 1 mm particle size.

2.3. Sorghum

2.3.1. Genotypes and experimental design for MStV studies

Three genotypes of sorghum, M 35-1, ICSV 93046 and 745, were investigated in the MStV experiment. The effect of MStV on the yield of sorghum stover and grain was determined in a field trial conducted during the 2000 post-rainy season (November–April). Each genotype was planted in eight rows of 4 m length with three replicates. Four border rows were planted on either side of each plot to avoid insecticide drift. Each plot was covered with a nylon mesh net of 6 m width, 4 m length and 2 m height to restrict movement of insects from one plot to another.

Adult plant hoppers were collected using aspirators from sorghum plants of genotype CSH 9 showing

MStV symptoms. Inoculation occurred 20 days after emergence by transferring 4–5 viruliferous adults into the whorls of each plant with the help of a camel brush. The inoculation was repeated after 10 days. Plants in control plots were not inoculated but carbofuran granules were placed in whorls 20 days after emergence followed by insecticide spray to control plant hoppers. Total number of plants and the number of plants showing symptoms of MStV were counted at 7-day intervals until harvest to determine the progress of disease incidence in each plot. At physiological maturity, leaves, stems and panicles of all plants were collected from the central four rows of each plot. The leaves and stems were dried at 50 °C until constant weight, ground and then used for laboratory analysis. Panicles were threshed from each plot and the grains were sun-dried. Dry weights of the grains were recorded and yields per hectare calculated.

2.3.2. Genotypes and experimental design for anthracnose studies

Five genotypes, Bulk Y, H 112, IS 3089, Local FSRP and Yellow Jowar and six treatments were used in this experiment, which was conducted during the 1999 rainy season (June–October) on a Vertisol soil. The treatments consisted of: (1) minimum disease—no inoculation and intensive application of the fungicide Dithane M-45 at 0.2%, (2) maximum disease—inoculation and no fungicide application, (3) low disease—inoculation and subsequently strategically-timed fungicide application to maintain disease severity at a low level, (4) moderate disease—inoculation and subsequently strategically-timed fungicide application to maintain disease severity at a moderately high level, (5) high disease—inoculation and subsequently strategically-timed fungicide application to maintain disease severity at a high level, and (6) control—no inoculation and no fungicide application. For plant inoculation, *C. graminicola* was multiplied on sterilised sorghum grains in the laboratory, and 3–4 colonised sorghum grains were placed in the whorl of each plant 30 DAS (Pande et al., 1994). After inoculation, sprinkler irrigation was provided daily for 1 week to provide moisture for fungus multiplication and to induce infection and disease development.

A split-plot design was employed with treatments (disease levels) as the main plots and genotypes as subplots with three replications for each treatment. Each plot consisted of eight rows of 4 m length. Five plants in each treatment with uniform plant growth were tagged and scored on a 0–100% severity scale (percent leaf area damaged by anthracnose) at 7-day intervals starting from 10 days after inoculation until maturity. For descriptive stover quality assessments, severities of external (after removing all the floral parts) and internal stem discoloration (after splitting open the stem with a knife) were rated on a 1–9 rating scale (1: no discoloration either external or internal; 9: >75% discoloration either on external or internal stem). At physiological maturity, ten plants in each treatment were cut at the second node. Stems and leaves were separated and dried at 50 °C till constant weight and ground for laboratory analysis.

2.4. Laboratory analysis of fodder value of groundnut haulms and sorghum stover

Laboratory analyses were conducted at the animal nutrition laboratory of the International Livestock Research Institute's (ILRI) South Asia Project hosted by ICRISAT in Patancheru. For all analyses, air-dry samples were ground through a 1 mm mesh. Nitrogen (N) was determined by a auto analyzer (Technicon Auto Analyser) in air-dry feed material and was corrected for dry matter (DM). DM and ash were determined according to AOAC (1997). Neutral detergent fibre (NDF) was determined by the method of Van Soest and Robertson (1985) and sugar content in feed was analysed by the colorimetric method of Dubois et al. (1956).

Rumen inoculum for the in vitro incubations was obtained from two rumen cannulated steers (local Indian breed) kept on a diet based on crop residues. A mixture of rumen fluid and particulate matter (approximately 60:40) was collected into CO_2-filled thermos bottles, transferred to and homogenised in a household blender, and strained and filtered through glass wool. All handling of rumen inoculum was carried out under continuous flushing of CO_2. Portions of about 200 mg of each air dried sample were accurately weighed (in triplicate) into 100 ml calibrated glass syringes, fitted with plungers as described by Menke et al. (1979) but modified as described by Blümmel and Ørskov (1993). A total of 30 ml of medium consisting of 10 ml of rumen inoculum and 20 ml of an ammonium and sodium bicarbonate-mineral-distilled water mixture was injected into the syringes. Three blanks containing 30 ml of medium only were included at the beginning and at the end of the incubation syringes. Accumulating gas volumes were recorded after 24 and 48 h of incubation. In vitro digestibility was calculated as $15.38 + (0.8453 \times \text{ml of gas produced after 24 h}) + (0.595 \times \text{percentage of crude protein}) + (0.181 \times \text{percentage of ash})$ as described by Menke and Steingass (1988).

3. Results

3.1. Groundnut

3.1.1. Effect of disease management practices on the severity of foliar diseases

Significant differences ($P < 0.05$) in the severity of foliar diseases were observed between management practices and genotypes (Fig. 2). Severity of foliar diseases in all the genotypes was lowest (<3 rating on 1–9 rating scale) in intensive compared to other management practices. Under MM, foliar disease severities were moderate (rating around 5) in ICGV 91114, 92020 and TMV 2, but were low (rating 3.5) in genotype ICGV 92093. Severities of these diseases were higher (~8 rating) in ICGV 91114 and TMV 2, moderate (6 rating) in ICGV 92020 and low (4.7 rating) in ICGV 92093 under NM. The lowest foliar disease severities were recorded in genotype ICGV 92093 and the highest were found in ICGV 91114 under all the three management practices (Fig. 2).

3.1.2. Effect of foliar diseases on haulm and pod yields

Significant differences ($P < 0.05$) in haulm yields were recorded between management practices and genotypes. Higher haulm yields were obtained under intensive than other management practices. Under all

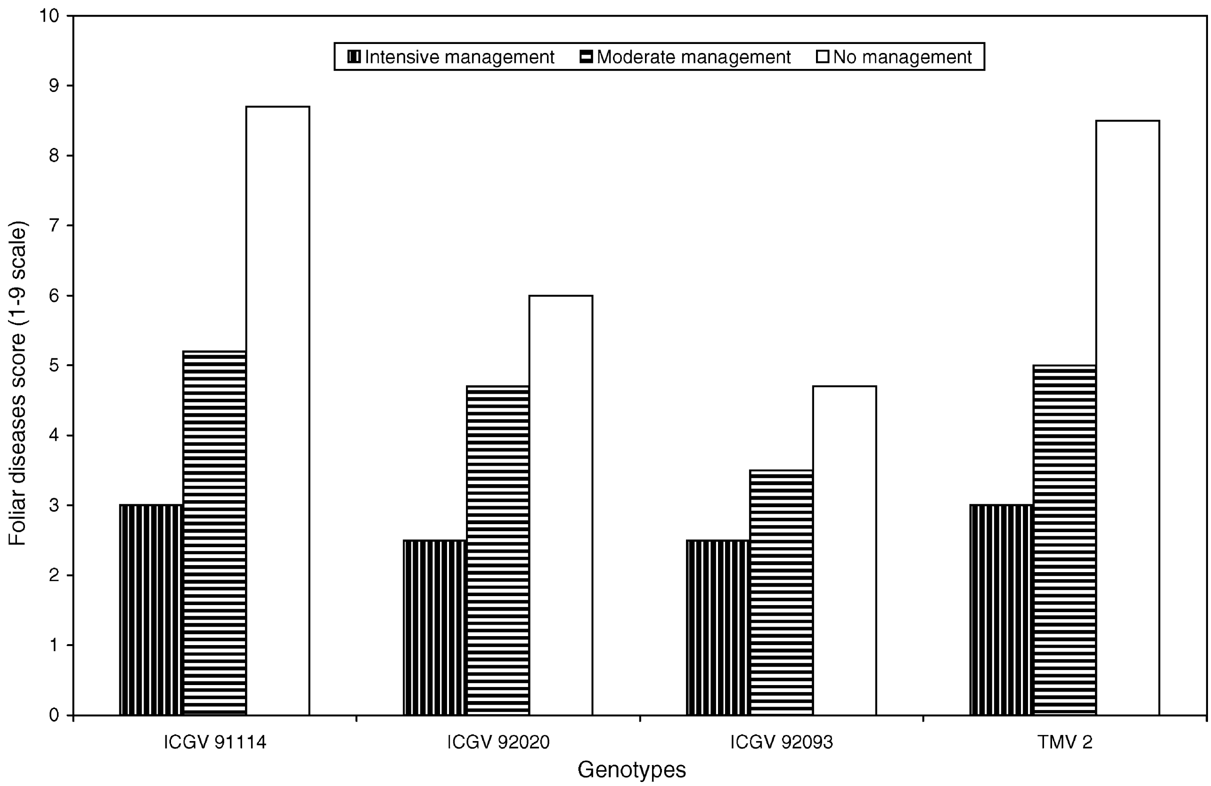

Fig. 2. Foliar disease scores (1: minimum and 9: maximum) of groundnut genotypes under three foliar disease management treatments. LSD ($P < 0.05$) 0.46 to compare all genotype × management treatment combinations.

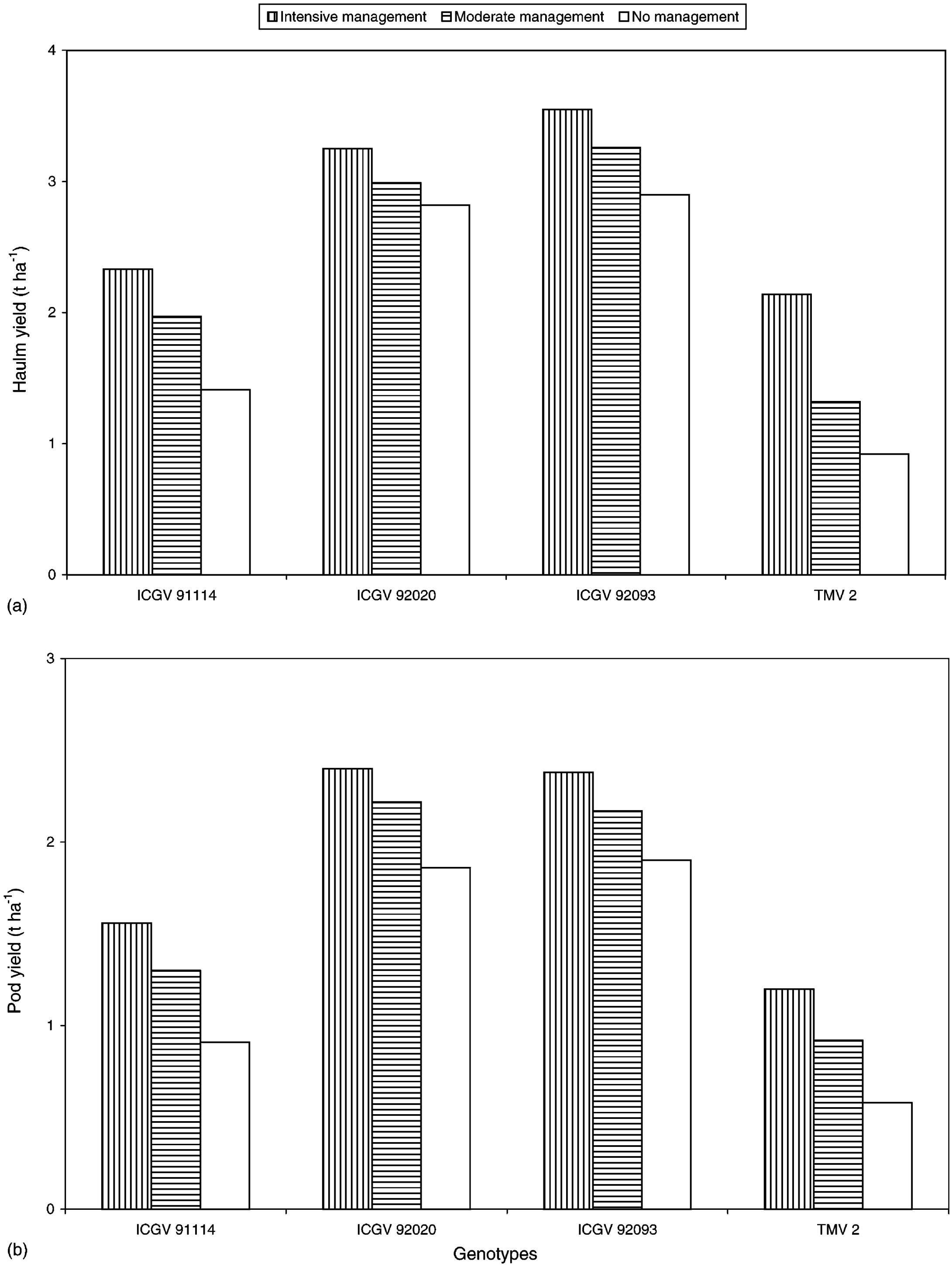

Fig. 3. (a) Haulm yields and (b) pod yields of groundnut genotypes under three foliar disease management practices. LSD ($P < 0.05$) to compare all genotype × management treatment combinations: 0.158 for haulm yield and 0.224 for pod yield.

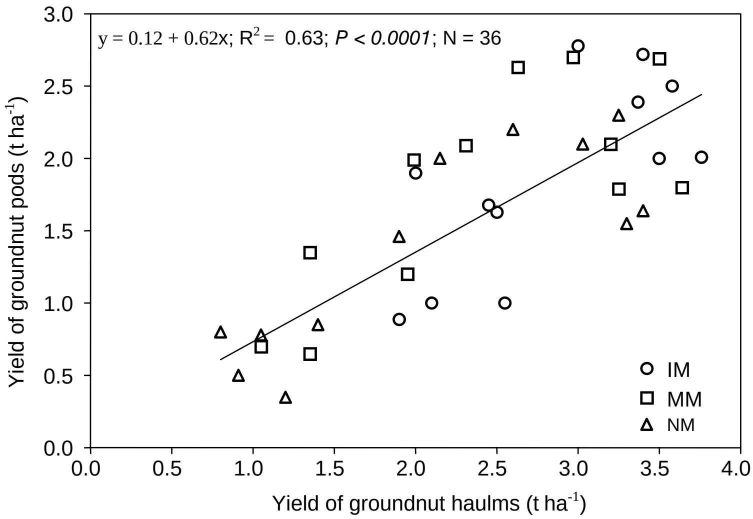

Fig. 4. Relationships between yield of groundnut haulms and groundnut pods across genotypes and disease management (individual field replications included). IM: intensive management, MM: moderate management, and NM: no management.

management practices, highest and lowest haulm yields were recorded in cultivars ICGV 92093 and TMV 2, respectively. Under NM, foliar diseases severely reduced haulm yields of ICGV 91114 and TMV 2. The haulm yield of ICGV 91114 and TMV 2 was increased by 40 and 47% by MM and 67 and 115%, respectively, by IM of the foliar diseases. Genotypes ICGV 92020 and 92093 retained much of their foliage under NM yielding 2.82 and 2.90 t ha^{-1} haulms, respectively. The yields of these two genotypes were significantly higher than yields of ICGV 91114 and TMV 2 under the IM practice (Fig. 3a).

Pod yields differed significantly ($P < 0.05$) between management practices and genotypes (Fig. 3b). No significant differences in pod yield were found between ICGV 92020 and 92093 under all three management practices. Highest pod yields were obtained in all genotypes under IM. Highest pod yields were observed in genotype ICGV 92020 under intensive (2.40 t ha^{-1}) and moderate (2.22 t ha^{-1}) managements, whereas ICGV 92093 gave highest yield (1.90 t ha^{-1}) under NM. Lowest pod yields were observed in TMV 2 (0.58 t ha^{-1}) and ICGV 91114 (0.91 t ha^{-1}) under NM. Pod yields in these two genotypes increased by 59 and 43% by moderate disease management and 107 and 71% by intensive disease management, respectively. The increase in pod yield in ICGV 92020 and 92093 was 19 and 29% by moderate disease management, and 14 and 25% by intensive disease management (Fig. 3b). Haulm and pod yield were highly significantly ($P < 0.0001$) associated even though considerable deviations ($Sy \cdot x = 0.43$) from the regression line were observed (Fig. 4). The regression coefficient suggested a mean biomass partitioning of pod to haulm of 0.38:0.62.

3.1.3. Effects of genotype and foliar diseases on the fodder value of groundnut haulms

Protein content and in vitro digestibility of genotypes under different management practices are reported in Table 1. Significant differences ($P < 0.05$) in

Table 1
Effect of genotype and foliar disease management on crude protein content and in vitro digestibility of groundnut haulms

Genotype	Protein (%)			Digestibility (%)		
	IM[a]	MM	NM	IM	MM	NM
ICGV 91114	13.6[b]	14.1	13.3	66.2	62.7	54.9
ICGV 92020	13.2	13.4	12.4	64.7	65.2	62.3
ICGV 92093	15.7	15.9	14.8	67.5	66.5	63.7
TMV 2	12.5	12.9	11.3	65.9	61.2	51.4
LSD ($P < 0.05$)	2.56			2.77		

[a] IM: intensive management; MM: moderate management; NM: no management/control.
[b] The mean values presented are the mean of three replications.

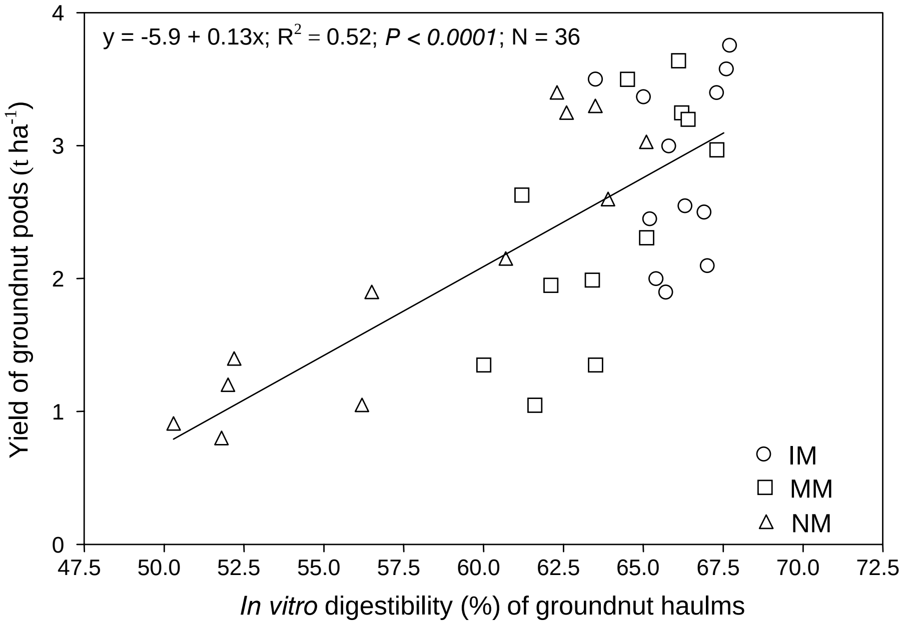

Fig. 5. Relationships between in vitro digestibility of groundnut haulms and yield of groundnut pods across genotypes and disease management (individual field replications included). IM: intensive management, MM: moderate management, and NM: no management.

protein content were observed between genotypes but not between management practices. Highest protein content was recorded in genotype ICGV 92093. Under low disease pressure, in vitro digestibilities were similar among all genotypes (Table 1). Foliar diseases significantly decreased in vitro digestibilities but genotypes were differently affected. While decreases in in vitro digestibilities were comparatively small in ICGV 92093 and 92020, substantial (>10%) reductions were observed for TMV 2 and ICGV 91114 (Table 1).

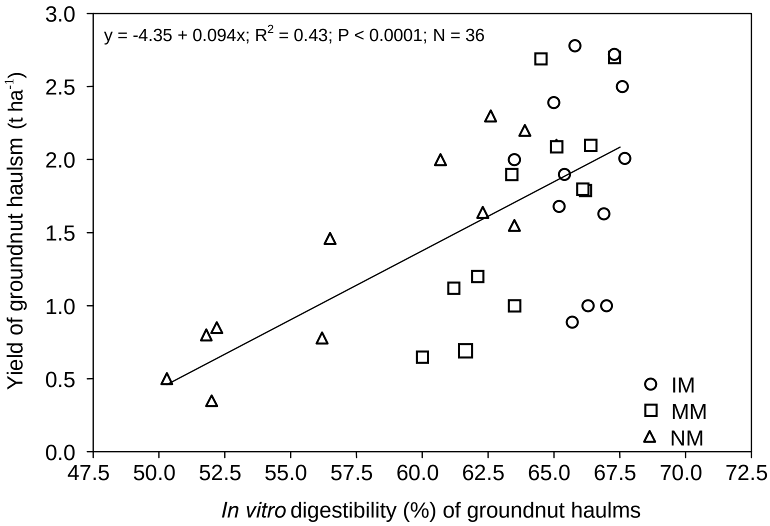

Fig. 6. Relationships between in vitro digestibility of groundnut haulms and yield of groundnut haulms across genotypes and disease management (individual field replications included). IM: intensive management, MM: moderate management, and NM: no management.

3.1.4. Relationship between fodder quality of groundnut haulms and pod and haulm yields

Fodder value of groundnut haulms and pod yield were not competitive traits and in vitro digestibility of groundnut haulms was positively ($P < 0.0001$) associated with pod yield (Fig. 5). Most of the in vitro digestibility values were in the range of 60 and 67% and pod yield in this range could vary by more than threefold. Similarly, in vitro digestibility of haulms was positively associated ($P < 0.0001$) with yield of haulms (Fig. 6).

3.2. Sorghum

3.2.1. Incidence of MStV and its effect on grain yield and total and digestible stover yield

Significant differences ($P < 0.05$) in mean cumulative incidences of MStV were observed between genotypes (Table 2). Mean cumulative incidence was 38% in ICSV 93046, 26% in M 35-1 and 18% in ICSV 745. MStV severity was higher in the initial 4 weeks than in later weeks, indicating that the vegetative growth stage of sorghum was more susceptible to MStV than the reproductive growth stage.

MStV could significantly depress both stover and grain yield but the level of depression was genotype-dependent (Table 3). Not surprisingly, reduction in digestible yield of healthy stover relative to the control was highest in ICSV 93046 (Table 3), the genotype with the highest disease incidence in inoculated plots (Table 2). Within disease-affected stover, reductions in digestible stover yield were greatest in ICSV 745 (Table 3). Symptomless plants in the control treatment had higher digestible straw yield than symptomless plants in the inoculated treatment for all genotypes.

Table 2
Mean cumulative incidence (%) of MStV during different weeks after inoculation in three sorghum cultivars[a]

Genotype	Time after inoculation (weeks)								
	1	2	3	4	5	6	7	8	9
ICSV 745	3.9	5.2	8.4	11.2	12.8	15.3	16.6	17.5	17.6
ICSV 93046	5.8	13.1	23.2	29.6	31.3	35.2	36.4	37.4	37.7
M 35-1	2.5	4.2	9.5	18.3	19.4	21.0	22.9	24.8	25.8
±S.E.M.	1.0	2.1	3.7	5.0	5.3	5.9	6.2	6.5	6.5

[a] The values presented are the mean of three replications. Plants were symptomless in non-inoculated control.

3.2.2. Incidence of anthracnose and its effect on grain and stover yield, on in vitro gas production and sugar and cell wall (NDF) content of stover

In the trial, Bulk Y and IS 3089 were damaged by birds and downy mildew, and hence excluded from further discussion in this paper. Fungicide application maintained a minimum disease level of anthracnose of <3% in all genotypes (Table 4). Without fungicide, susceptibility to anthracnose was highly genotype-dependent under all levels of anthracnose severity. In general, H 112 had the highest disease level followed by Local FSRP and Yellow Jowar.

The effects of anthracnose on grain and stover yield of the remaining three genotypes were variable (Table 5). In Yellow Jowar, treatments with low disease

Table 3
Effect of MStV on stover yield (SY), grain yield (GY) and digestible stover yield[a] of sorghum

Genotype	Treatment	Mean yield (t ha^{-1})		Digestible SY (t ha^{-1})	
		SY	GY	Symptomless	Infected
ICSV 745	Control	5.90	5.48	3.02	–[b]
ICSV 745	Inoculated[c]	4.59	4.67	2.55	1.40
ICSV 93046	Control	11.72	4.21	6.10	–
ICSV 93046	Inoculated	8.14	2.45	4.57	4.00
M 35-1	Control	8.83	3.64	4.42	–
M 35-1	Inoculated	8.26	3.20	4.07	4.90
LSD ($P < 0.05$)		1.49	0.73	0.73	0.76

[a] Based on plant populations of 133,500 ha^{-1}.
[b] Infected plants were not available since all plants were symptomless.
[c] Plants inoculated with plant hopper vectors collected from MStV-infected planted in the field.

Table 4
Percent leaf area of five sorghum genotypes damaged by anthracnose at maturity under different treatments to induce different disease severity

Treatment	Bulk Y	Yellow Jowar	H 112	Local FSRP	IS 3089
Minimum disease	1.7[a]	1.9	1.1	2.9	0.5
Maximum disease	66.7	93.3	100.0	93.3	44.0
Low disease	28.0	33.0	57.3	33.3	26.3
Moderate disease	47.7	52.0	71.7	48.3	32.7
High disease	65.3	74.0	86.3	75.0	46.7
Natural	56.67	18.33	79.0	19.7	28.3
LSD ($P < 0.05$)	9.77				

[a] Mean of three replications.

Table 6
In vitro gas volumes (GVs) (ml 200 mg^{-1}) for 48 h, sugar content (%, SUG) and cell wall content (%, NDF) in leaves and stems of stover from five genotypes of sorghum

Genotype	Stover leaves			Stover stems		
	GV	SUG	NDF	GV	SUG	NDF
Bulk Y	38.2	8.0	56.3	33.8	19.6	57.8
H 112	35.4	7.1	62.2	28.0	17.7	66.0
IS 3089	32.3	4.7	66.7	24.5	14.5	71.5
Local FSRP	33.3	7.3	60.2	23.8	17.12	66.3
Yellow Jowar	32.1	7.4	59.7	26.2	16.4	67.5
Mean	34.3	6.9	61.0	27.3	17.1	65.8
±S.E.M.	0.1	0.25	0.72	0.1	0.63	1.1

levels (low disease and natural treatments) had significantly more grain yield compared to treatments with very low (minimum disease) or very high disease levels (maximum disease and high disease treatments). The stover yield of Yellow Jowar was significantly lower under maximum and natural disease regimes compared to minimum disease. Grain and stover yields of H 112 in all treatments without fungicide protection were significantly lower than the minimum disease treatment. In Local FSRP, the maximum disease treatment had lower grain yield than the minimum disease treatment, but stover yield was statistically similar in all treatments.

In vitro gas production, sugar and cell wall (NDF) content of the genotypes are reported in Table 6. Significant genotype-dependent differences were found in these laboratory quality indicators. In vitro gas production was lower in stems than in leaves while sugar and NDF content were higher in stems than in leaves (Table 6). In vitro digestibility was significantly lower in the maximum disease treatment compared to the minimum disease treatment. In general, however, anthracnose had very little effect on laboratory quality indicators and differences between measurements under minimum and maximum disease level were small (Table 7). Similarly, quality indictor means across genotypes and disease levels were very similar to those observed in healthy sorghum.

4. Discussion

Livestock rearing has great potential for improving livelihoods in the SAT of Asia and Africa but major constraints, notably shortage of fodder, need to be alleviated (McIntire et al., 1992; Delgado et al., 1999).

Table 5
Effect of anthracnose on grain (t ha^{-1}, GY) and stover yields (t ha^{-1}, SY) of sorghum cultivars under different anthracnose severity

Treatment	Bulk Y		Yellow Jowar		H 112		Local FSRP		IS 3089	
	GY	SY	GY	SY	GY	SY	GY	SY	GY	SY
Minimum disease	1.64[a]	5.59	3.99	13.27	3.66	16.32	4.57	12.19	1.61	8.87
Maximum disease	1.86	4.64	3.88	11.60	1.94	12.57	3.79	11.55	2.44	8.08
Low disease	2.21	5.56	4.68	12.11	2.79	13.18	4.28	11.93	2.47	10.17
Moderate disease	1.97	4.47	4.26	11.98	2.86	12.83	3.42	11.79	2.37	7.72
High disease	2.05	4.67	4.01	10.86	2.49	12.12	3.85	11.67	2.76	8.34
Natural	1.95	5.20	4.77	11.46	2.77	13.85	4.09	11.15	2.64 7	90
LSD of GY ($P < 0.05$)	0.52									
LSD of SY ($P < 0.05$)	1.52									

[a] The values presented are the mean of three replications.

Table 7
Effect of anthracnose on mean in vitro gas volumes (GVs) (ml 200 mg^{-1}) for 48 h, sugar content (%, SUG) and cell wall content (%, NDF) in leaves and stems of stover of five sorghum cultivars under different anthracnose pressures

Treatment	Stover leaves			Stover stems		
	GV	SUG	NDF	GV	SUG	NDF
Minimum disease	34.9[a]	7.6	61.0	29.4	17.0	65.1
Maximum disease	33.1	6.6	61.1	28.4	17.0	65.1
Low disease	35.9	7.2	60.3	28.9	18.3	64.7
Moderate disease	34.9	7.1	62.4	26.3	16.9	66.7
High disease	34.9	6.9	60.9	25.7	16.7	66.0
Natural	31.9	6.0	60.7	24.1	16.4	67.5
Mean	34.3	6.9	61.0	27.3	17.1	65.8
±S.E.M.	0.1	0.4	0.7	0.1	0.5	1.4

[a] Mean of three replications.

Crop residues are very important fodder resources in these areas. during the last decade several crop improvement programs have embarked on breeding of dual-purpose genotypes, that is genotypes with good grain yield and good fodder value in the crop residues (Reddy et al., 1995; Rattunde, 1998). Since then, genotypic effects on crop residue value have been studied in some detail (Zerbini and Thomas, 1999; Blümmel et al., 2003a,b) but the effects of plant diseases on crop residue value have, until very recently (Bandyopadhyay et al., 2001), received little attention.

The fact that plant diseases also affect crop residue value was brought to the attention of plant and animal scientists through participatory rural appraisals and stakeholder workshops where farmers and fodder traders voiced considerable concerns about these adverse effects on crop residue value (Rama Devi et al., 2000; Bandyopadhyay et al., 2001). The work presented here was undertaken in response to these concerns and focused on the two major crops on the Deccan Plateau study area in India—groundnut and sorghum.

LLS and rust were identified as the two prevalent and most important foliar diseases of groundnut on the Deccan Plateau (Pande et al., 2001). The high adverse effect of foliar diseases on pod and haulm yield as well as on haulm quality is confirmed by the present work. These diseases together could result in almost complete defoliation (score 9) in susceptible genotypes ICGV 91114 and TMV 2 unless fungicide was applied (Fig. 2). Considerable host plant resistance was shown in genotype ICGV 92093 and, to a lesser extent, in ICGV 92020 (Fig. 2). In the four genotypes investigated, the best control of foliar diseases was achieved by a combination of genetic resistance and fungicide application. Resistance to foliar diseases was positively associated with pod and haulm yields (compare Figs. 2 and 3).

Haulm quality, estimated by in vitro digestibility measurements, was clearly affected by foliar diseases (Table 1). While under IM haulms maintained very high in vitro digestibility, it significantly decreased as foliar disease severity increased (Table 1). Foliar diseases caused defoliation of leaves thereby decreasing the leaf:stem ratio. Disease lesions also damage the stem. In a groundnut plant, the leaf fraction has more crude protein and soluble and degradable DM, and better in vitro digestibility compared to the stem fraction (Larbi et al., 1999). Therefore, disease-induced losses in mass of the better quality leaf fraction result in significant losses in digestibility of disease-affected plants. In tropical fodder plants too, diseases substantially lower DM production and feed quality parameters. Losses of 17% in digestibility, 30% in nitrogen content and 42% in K content have been reported in scald (*Monographella albescens*) affected leaves of *Andropogon gayanus* (Lenné and Calderon, 1989). Moreno et al. (1987) found that Camptomeris leaf spot (*Camptomeris leucaenae*) reduced crude protein content by 11 and 18%, respectively, in moderately and severely affected foliage of *Leucaena*. In similar studies with *Stylosanthes*, anthracnose (*C. gloeosporioides*) affected plants had 14 and 22% less crude protein, respectively, in moderately and severely affected foliage of *Stylosanthes guianensis* compared to the healthy control (Lenné, 1986).

No competition was observed between haulm yield and pod yield (Fig. 4), haulm quality and pod yield (Fig. 5), and haulm quality and haulm yield (Fig. 6). All these relationships were highly positive, that is, high haulm quality was associated with high pod and haulm yields. In fodder quality studies with 38 late-maturing groundnut genotypes, Larbi et al. (1999) concluded that forage and seed yields were significantly correlated ($r = 0.53$), but seed yield was poorly correlated with forage quality indices examined. However, based on yield (haulm and seed) and in vitro digestibility, these workers identified some cultivars with high, medium, and low potential for seed and forage production suggesting that it is possible to select for high yield and feed quality. Subsequently, Etela et al. (2000) found that voluntary intake, in vitro digestibility, nitrogen retention and daily live weight gain varied significantly among groundnut genotypes fed to West African dwarf sheep. The groundnut genotypes MI70-80I, UGA-5, and M72-80I combined high haulm and pod yields, and sheep live weight gains. They concluded that these genotypes could be used in mixed livestock systems to increase crop and livestock outputs in Nigeria.

In our studies, highly significant differences were found between the effect of disease management and genotypes on in vitro digestibility. Foliar disease resistant genotypes ICGV 92020 and 92093 maintained a digestibility of >60% even under NM (high disease pressure) while in this treatment in vitro digestibility of susceptible genotypes ICGV 91114 and TMV 2 decreased to 54 and 51%, respectively (Table 1). The decrease in nutritive quality of diseased TMV 2 haulms observed in vitro was confirmed by a feeding trial using buffalo (Ramateke et al., 2003b). In vivo organic matter was 61.7% in healthy TMV 2 haulms produced under the IM treatment, but only 55.4% ($P < 0.05$) in diseased haulms produced under the NM treatment. Similarly, voluntary feed intake relative to live weight was 2.6% in healthy TMV 2, but only 1.7% ($P < 0.05$) in diseased haulms (Ramateke et al., 2003b). To conclude, choice of appropriate genotypes with foliar disease resistance can assure high haulm quality even without fungicide application. In groundnut there appears to be, therefore, a real opportunity for breeding and selection of superior disease resistant, dual-purpose genotypes that provide excellent pod and haulm yield and, additionally, very high haulm quality.

Major important diseases in sorghum were MStV and anthracnose (Indira et al., 2002; Narayana et al., 2002). MStV incidence was highly genotype-dependent with genotypes ICSV 93046, M 35-1 and ICSV 745 showing high, medium and low susceptibility to MStV, respectively (Table 2). The virus could significantly reduce grain yield, total stover yield and digestible stover yield (Table 3) and these reductions were highest in the most susceptible genotype. Therefore, infection with MStV can reduce farmers' livelihoods from sorghum cropping by reducing revenue from grain as well as from stover utilisation through feeding and fodder trading. However, decisions on choice of sorghum genotype for MStV-prone areas will depend on the relative value of grain and stover. Thus ICSV 745 maintained high grain yield also under inoculation with MStV but its digestible stover yield was lowest among the three genotypes in both the control and inoculation treatments (Table 3). The final choice between genotypes ICSV 745 and 93046 should, therefore, depend on the respective economic revenue from grain and stover. More work is required to define economic trade-off scenarios between grain and stover in different socio-economic environments.

Our studies indirectly suggest that plant hopper damage can also reduce digestibility since the digestible stover yield of symptomless plants in the inoculated treatment was lower than that of the control treatment. Viruliferous plant hoppers were released in the inoculated treatment, but virus symptoms were not observed on all plants. However, plant hoppers damaged most of the plants, including plants without virus symptoms. No plant hopper damage occurred in the control treatment. Therefore, the difference in digestible stover yield of the symptomless plants of inoculated and control treatments can be partially attributed to plant hopper damage. Participatory rural appraisal studies of Rama Devi et al. (2000) in the Deccan plateau documented farmers' perceptions of insect damage as a potential contributor to losses in stover quality and marketability. Other plant parasites such as *Striga hermonthica* are also known to reduce digestibility of maize in West Africa (Larbi et al., 1998). More research is required to understand the effect of damage by insect pests and other parasites on stover yield and quality.

As with MStV susceptibility, anthracnose severity among the five genotypes of sorghum was genotype-dependent (Table 4). While fungicide application suppressed anthracnose efficiently in all genotypes (minimum disease: Table 4), severity under natural conditions varied from 18% in Yellow Jowar to 79% in H 112. The susceptibility of H 112 to anthracnose was clearly reflected in the high reduction in grain and stover yield of this genotype in the presence of anthracnose. Interestingly, two of the local genotypes of sorghum—Yellow Jowar and Local FSPR—had some degree of tolerance to anthracnose since the losses in grain and stover yield was less than the susceptible genotype H 112 under maximum disease pressure (Table 5). Yellow Jowar under low to moderate disease pressure induced production of grain-bearing nodal tillers that contributed to increased grain yield compared to the minimum disease pressure treatment. Therefore, tillering appears to be a factor that more than compensated for foliage damage by anthracnose.

Stover value to farmers is the product of quantity and quality, i.e., digestible stover yield. In vitro gas production after 48 h of incubation in rumen fluid and sugar content are considered to be positive quality indicators while cell wall content (NDF) is regarded as a negative quality indicator. Significant genotype-dependent differences in these quality indicators were found (Table 6). Yellow Jowar and Local FSRP exhibited in vitro gas volume, sugar and NDF values that were close to the overall mean values across the five genotypes, suggesting that in sorghum stover quality is not necessarily inversely related to grain and stover yield. This agrees with data reported by Blümmel et al. (2003a).

In the present study anthracnose had surprisingly little effect on above described laboratory quality indictors, although in vitro digestibility was significantly reduced by the maximum disease level compared to the minimum disease level (Table 7). Decreases in feed quality attributes were most pronounced in the susceptible genotype H 112 (data not shown). The influence of anthracnose on forage quality was first explored in sudan grass (*Sorghum* × *drummondii*) by Burton (1954) who reported that 10% diseased leaves resulted in 9% loss in protein and fat, and 20% gain in lignin content in the herbage. Gandhi et al. (1980) found that leaf diseases, of which anthracnose was a component, affected quality attributes of leaves of two forage sorghum genotypes in northern India. Intensity of leaf diseases was negatively correlated with crude protein content and in vitro digestibility and positively correlated with silica and lignin content (Gandhi et al., 1980). Therefore, diseases of dual-purpose crops such as sorghum can significantly affect DM yield and nutritive value of feed.

As pointed out by Blümmel et al. (2003b) some putative laboratory quality indicators of sorghum stover, notably sugar content, need to be revisited if applied to whole stover analysis. As shown in Table 6, the sugar content in sorghum stems was more than twice that in sorghum leaves. Ranking of whole stover from different genotypes by sugar content could, therefore, result in selection of genotypes with a high proportion of stem. Stover from these genotypes faces a high rejection rate by the animals, which prefer leafy over stemmy roughages. In a connected piece of research, Ramateke et al. (2003a) compared in vivo digestibility and voluntary feed intake of healthy (produced by intensive application of fungicide as in minimum disease treatment) and severely anthracnose-damaged (inoculated as described for maximum disease treatment) sorghum stover of the genotype H 112 in buffalo. They found significant ($P < 0.05$) reductions in intake (1.70 vs. 1.85% of live weight of buffalo) and in vivo digestibility (44.2 vs. 48.3%) in diseased compared to healthy stover. These data support the assumption of Bandyopadhyay et al. (2001) that anthracnose can reduce not only grain and stover yield but also stover quality.

5. Conclusions

Our studies document clear negative effects of plant diseases on grain/pod and stover/haulm yields but these effects can be substantially reduced by choice of appropriate genotypes and plant protection measurements. In groundnut, two genotypes were identified that maintained high pod yield, haulm yield and haulm quality under high disease pressure of LLS and rust even with no usage of fungicide. Similarly, MStV and anthracnose could significantly reduce grain and stover yield in sorghum but the degree of yield reduction was strongly genotype-dependent. The effect of these plant diseases on stover quality was less clear but indications were found that MStV and anthracnose could not only reduce stover quantity but also quality in susceptible genotypes.

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