Evaluation Of Intercropping for the Management Of The Stem Borer *Coniesta ignefusalis* Hampson and The Head Miner *Heliocheilus albipunctella* de Joannis in Different Varieties Of Pearl Millet In The Nigerian Sudan Savanna

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Abstract

Two field trials were conducted in 1997 and 1998 cropping seasons in Maiduguri, northeastern, Nigeria, to assess damage by the stem borer Coniesta ignefusalis and the head miner Heliocheilus albipunctella in Ex-borno, Zongori, Wame, Gargasori, Mboderi and GB8735 millet varieties sown as sole crops and also as intercrops with cowpea (cv. Borno brown) or sorghum (cv. Gooseneck). Damage in Ex-borno arranged in a row with cowpea or sorghum in cropping patterns of 3:1, 2:1, 1:1 and 1:0 was also assessed. Both trials were sown on July 14. The stem borer caused significantly lower damage (number of emergence holes and larval tunnels) in sole millet and higher damage in millet intercrops in 1997. Mboderi in 1997 and Ex-borno in 1998 suffered significantly more tunnelling from the borer than the other varieties; in contrast, GB8735 suffered the lowest damage in 1997. Gargasori, sown as sole crop or as intercrop, was not infested by head miners in 1997. However, significantly higher numbers of head miner larvae infested sole Ex-borno in the same year. Grain yields were significantly higher in Zongori than in the other varieties in both 1997 and 1998; yields were lowest in GB8735 intercropped with cowpea in both years. The stem borer caused significantly higher damage to millet in the 1:1 pattern in 1997 and in the 2:1 pattern in 1998. Similarly, the head miner caused significantly higher damage to millet in the 3:1 pattern in 1998. Grain yields were significantly higher in 1:0 and lower in 1:1 patterns in both 1997 and 1998. Grain yields in the millet-cowpea were significantly higher in 1997 and lower in 1998 than in the millet-sorghum intercrop system.

Key words: Pest management, intercropping, millet varieties, stem borer (*Coniesta ignefusalis*), head miner (*Heliocheilus albipunctella*), Nigerian savanna

Introduction

Millet is a major food crop in the sahelian parts of Africa and Asia. The crop is of marked regional importance in West Africa; Nigeria is the world's second largest producer after India (Aminu-Kano *et al.* 1998). The stem borer, *Coniesta ignefusalis* Hampson (Lepidoptera: Pyralidae) and the head miner *Heliocheilus albipunctella* de Joannis (Lepidoptera: Noctuidae) are major pests of pearl millet *Pennisetum glaucum*

(L.) R. Br. in the savanna areas of West Africa (Ajayi 1984; 1985a; 1985b; 1990; Youm and Gilstrap 1993; Nwanze 1991; Nwanze *et al.* 1995; Youm 1995; Ajayi *et al.* 1998). The taxonomy and bioecology of the pests are well described (Harris, 1962; Matthews 1987; Ndoye and Gahukar 1987; Nwanze and Sivakumar 1990; Youm and Gilstrap 1993; Gilstrap *et al.* 1995; Nwanze *et al.* 1995).

The stem borer larvae cause dead hearts in millet seedlings and tunnel the stems of other millet plants while young larvae of the head miner destroy millet floral glumes and mature larvae damage floral spikelets (floral peduncles) producing spiral mines in crop panicles (Harris 1962; Ajayi 1984; 1990; Jago 1995; Krall *et al.* 1995; Nwanze *et al.* 1995; Youm and Kumar 1995). Panicle infestation of up to 75% and grain yield loss of up to 85% have been attributed to the millet head miner (Gahukar *et al.* 1986; Krall *et al.* 1995); the range of infestation for Nigeria has been reported to be 6.5-51.0% (Deeming 1978; Ajayi 1981; 1984), with as many as 8 larvae/panicle (Buahin *et al.* 1998). On the other hand, the millet stem borer is known to be capable of causing complete crop failure (Dike and Ajayi 1997). Nevertheless, reports of diagnostic research for the assessment of on-farm damage and losses attributable to *C. ignefusalis* are scanty in the literature. Also, the head miner has already been confirmed as a major problem in Nigeria (Ajayi 1984); however, crop loss associated with the pest has not been substantially studied (AjayI *et al.* 1998).

In the Nigeria savanna, the farming system consists of combinations of various crops on a subsistence farm (Steiner 1984; Olabanji *et al.* 1995; Umaru *et al.* 1998). Nevertheless, the degree of the diversity of a system determines the level of insect herbivory that a species suffers in the system (plant community); insect herbivory is slight in highly diverse systems (polycultures) and drastic in systems with low diversity (monocultures) principally because intercompensatory factors such as predation are highly operative in diverse systems and virtually lacking in monocultures (Hodkison and Hughes 1982). Thus, a diverse multiple cropping creates a more stable environment for pests (Van Emdem and Williams 1974; Steiner 1984). This work assessed the effects of intercropping systems on the relative susceptibility to the stem borer and the head miner of six of the millet varieties that are commonly grown in the sudano-sahelian zones of Nigeria.

Materials and Methods

Two field trials were carried out in Maiduguri (northeastern Nigeria) (Latitude 11º50´ N and Longitude 13 º05´ E) during the 1997 and 1998 cropping seasons. Six varieties of millet, 1 of sorghum and 1 of cowpea obtained from the North-East Arid Zone Development Programme, Gashua, Nigeria and the Lake Chad Research Institute, Maiduguri, Nigeria, were used as planting materials.

The experiments
The first experiment consisted of six millet varieties: Ex-borno, Mboderi; Gargasori; Zongori; Wame; GB8735, sown as sole crops and also in mixture with cowpea (cv. Borno brown) or sorghum (cv. Gooseneck) in a 6 x 3 factorial experiment. The six millet varieties formed the main plot treatments and the three cropping systems of millet-cowpea, millet-sorghum and sole millet formed the subplot treatments. Each of the 18 treatment combinations was allocated to a plot of 4 m x 6 m. There were four

rows of millet in each plot spaced at 1 m intervals. In each row of intercropped millet treatment, cowpea or sorghum, spaced at intervals of 50 cm, were sown 75 cm away from stands of millet while in each row of sole millet sowing was at 1 m interval between millet stands. In the second experiment, the same cowpea or sorghum varieties used in the first experiment were sown into Ex-borno millet. The factorial arrangement was two cropping systems of millet-cowpea and millet-sorghum as main plot treatments and four cropping patterns of 3:1, 2:1, 1:1 and 1:0 millet to either cowpea or sorghum. Each of the eight treatments was allocated to a plot of 4 m x 11 m. There were four rows of millet in each plot spaced at 1 m intervals. In each row, the spacing was 1m between millet stands and 75 cm between millet and cowpea or sorghum stands in intercropped millet plots; cowpea or sorghum stands were spaced 50 cm within the row. Millet stands were spaced at intervals of 1 m in sole millet plots. Each of the two experiments was laid out in strip plot design and replicated three times.

All experiments were sown on 14 July. Plots were weeded twice at 3 and 6 weeks after sowing and seedlings were thinned to two per pocket. NPK 15:15:15 fertilizer was applied at the rate of 64 kg /ha N, P_20_5 and K_20 at sowing and urea 4 weeks later to the cereal component in accordance with the recommendation of the Borno State Agricultural Development Programme (BOSADP) (1993).

Assessment of damage due to stem borer

Infestation (percentage of stems bored and percentage of internodes bored) and damage (number of emergence holes and larval tunnel lengths) by *C. ignefusalis* were assessed (from ten millet stems collected randomly from the two outer rows in each plot) at time of harvest, following the methods of Ajayi, (1985b) and Ajayi and Labe, (1990) as stated below:

- Mean percentage numbers of stems bored per sample = (number of millet stems with holes in sample/total numbers of stems sampled) x 100
- Mean percentage numbers of internodes bored per stem = (numbers of internodes bored in sample/total numbers of internodes sampled) x 100
- Mean numbers of emergence holes per stem = number of emergence holes in sample/total number of stems sampled
- Larval tunnel length (cm) per stem = length of tunnel measured in sample/total numbers of stems sampled.

Sampling and assessment of damage per grain yield loss due to head miner

Larvae of *H. albipunctella* were collected weekly, beginning from the booting stage (flowering), from millet heads in the two outer rows of each plot in the early mornings (0500-0600 GMT) to reduce the effects of larval migration (Youm 1995), taking care not to disturb those on panicles in the two inner rows (millet heads from the inner rows were used for damage, grain yield and grain yield loss assessment). The soil surface directly under the millet plants were checked regularly for larvae that fell off the panicles. Insects were later identified, counted and preserved in 70% alcohol. The identity of the adult moth was eventually confirmed at the Insect Museum of the Institute for Agricultural Research, Ahmadu Bello University, Zaria, Nigeria.

Millet head damage and grain yield loss caused by *H. albipunctella* were assessed according to the adjusted length method of Coop *et al*., (1993) and as outlined in Sastawa *et al*., (2002) as follows:

- Head length damaged (%)/pocket by head miner = Adjusted damaged length (ADL)/Pocket x 100
- Total adjusted length (TAL)/Pocket Grain yield loss/ha (%) = Yield loss (kg/ha) due to head miners x 100
- Actual yield obtained + yield loss (kg/ha) i.e. Grain yield (kg/ha) = Yield/pocket (kg) x number of harvestable pockets/ha

Data analysis

Data on head miner count and associated percentage damage and grain yield loss were transformed using the square root ($\sqrt{\ (x + 1)}$) transformation before analysis. All data were then subjected to ANOVA and significant ($p < 0.05$) differences between means were determined using the Duncan's Multiple Range Test (DMRT).

Results

Table 1 shows that infestation by the stem borer was significantly higher in the millet-cowpea intercrop system than in the other systems in 1997; however, only percentage internodes bored was significantly higher in millet-cowpea than in the other cropping systems in 1998. Similarly, borer damage was significantly higher in millet-cowpea intercrop system than in sole millet system in 1997 but there were no such differences between the systems in 1998. Grain yield significantly differed between the cropping systems only in 1997, with the yields in sole millet > millet-cowpea > millet-sorghum. Grain yield was, however, highly negatively correlated with tunnel length in 1997 (r = -0.92) and 1998 (r = -0.98). Mean number of holes/ stem was significantly higher in Gargasori than in the other varieties in 1997 and in Ex-borno or Gargasori than in GB 8735 or Mboderi in 1998. Mean tunnel length was significantly longer in Mboderi in 1997 and in Ex-borno in 1998 than in the other varieties. Grain yield was significantly higher in Zongori and lower in GB8735 than in the other varieties in both 1997 and 1998.

Furthermore, the mean percentage of stem bored per sample was significantly higher in Zongori or Ex-borno intercropped with cowpea than in the other treatments except sole Mboderi or GB8735 and Mboderi intercropped with sorghum or Wame intercropped with cowpea in 1997 (Table 2). In 1998, the percentage was significantly higher in Ex-borno intercropped with cowpea than in the other treatments except Zongori intercropped with cowpea (Table 3). Percentage internodes bored was significantly higher in GB 8735 intercropped with cowpea than in the other treatments in 1997 while in 1998, the percentage was significantly higher in sole Wame or in Ex- borno intercropped with cowpea than in the other treatments except Wame or Zongori intercropped with cowpea. Damage was significantly higher in Mboderi intercropped with sorghum than in the other treatments in 1997. In 1998, number of emergence holes per stem was significantly higher in Ex-borno intercropped with cowpea than in the other treatments except sole Ex-borno or Wame and Gargasori or Zongori intercropped with cowpea. Mean tunnel length was significantly longer in Ex-borno intercropped with cowpea than in the other treatments. Grain yield was significantly higher in sole Zongori than in the other varieties in 1997. In 1998, grain yield was higher in both sole and intercropped Zongori as well as in sole Mboderi or Gargasori and in Wame intercropped with cowpea or Gargasori intercropped with sorghum than in the other varieties.

Table 1. Effects of variety and cropping system on stem borer damage and grain yield of millet in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.)

Treatment	Mean percentage of stems bored/sample	Mean percentage of internodes bored/stem	Mean number of emergence holes/stem	Mean larval tunnel length (cm)/stem	Mean grain yield (kg/ha)
			1997		
Varieties					
Ex-borno	40.69a	35.11b	1.200c	5.57b	279.69b
Mboderi	26.40a	51.00a	1.600b	11.73a	293.34b
Gargasori	38.93a	18.27c	1.97a	2.68cd	208.71c
Zongori	33.12a	21.92c	1.08d	5.90b	353.74a
Wame	36.57a	30.58b	0.83e	3.77c	291.12b
GB8735	16.67a	46.79a	0.32f	1.63d	114.33d
Std error of the mean	13.17	2.85	0.03	0.69	20.82
Cropping system					
Millet-cowpea	51.48a	45.38a	1.65a	6.61a	230.29b
Millet-sorghum	28.90b	23.22c	1.07b	6.41a	144.14c
Sole millet	26.92b	33.23b	0.78c	2.62b	356.04a
Std error of the mean	7.53	2.04	0.09	0.62	10.81
Interaction	Sig.	Sig.	Sig.	Sig.	Sig.
		1998			
Varieties					
Ex-borno	64.22a	30.79a	6.71a	37.43a	279.29c
Mboderi	32.17b	16.41b	2.22b	12.50b	392.56b
Gargasori	47.89ab	28.o2ab	5.72a	14.30b	379.60b
Zongori	53.33ab	22.56ab	4.39ab	12.82b	508.42a
Wame	43.28ab	33.72a	4.24ab	13.31b	396.64b
GB8735	45.56ab	15.29b	2.69b	11.78b	211.00c
Std error of the mean	11.96	6.39	1.13	5.15	39.87
Cropping system					
Millet-cowpea	47.22a	30.00a	5.52a	18.28a	305.94a
Millet-sorghum	50.28a	22.52b	3.09a	16.51a	390.73a
Sole millet	45.72a	20.88b	4.15a	16.28a	387.09a
Std error of the mean	11.05	0.72	0.89	2.92	35.04
Interaction	Sig.	Sig.	Sig.	Sig.	Sig.

Table 2. Effect of interaction of variety and cropping system on stem borer damage and grain yield of millet during the 1997 cropping season in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test.)

Treatment	Mean percentage of stems bored/sample	Mean percentage of internodes bored/stem	Mean number of emergence holes/stem	Mean larval tunnel length (cm)/stem	Mean grain yield (kg/ha)
Ex-borno x cowpea	72.07a	45.80de	2.00cd	7.90cd	396.46cd
″ x sorghum	25.00bc	32.43fg	1.30ef	6.70de	152.90eg
″ x sole	25.00bc	27.10hi	0.30gi	2.10gh	289.73de
Mboderi x cowpea	25.00bc	29.10h	0.60gi	3.10g	168.67eg
″ x sorghum	37.50ac	68.73b	4.00a	27.400a	132.98fg
″ x sole	16.50bc	55.16bc	0.20hi	4.70f	578.36ab
Gargasori x cowpea	62.50ab	0.01k	2.50bc	0.03i	215.48eg
″ x sorghum	22.00bc	15.93i	0.70fh	2.40g	150.82eg
″ x sole	32.30ac	38.87fg	2.70b	5.60ef	259.82df
Zongori x cowpea	74.33a	51.70c	2.90b	17.50b	288.25de
″ x sorghum	0.03c	0.01k	0.03i	0.00i	136.30fg
″ x sole	25.00bc	14.07j	0.30g	0.20hi	636.68a
Wame x cowpea	62.50ab	47.20de	1.80de	8.50c	222.80eg
″ x sorghum	22.20bc	22.23i	0.40gi	2,00gh	177.66eg
″ x sole	25.00bc	22.30i	0.30gi	0.80hi	472.91bc
GB8735 x cowpea	12.50c	98.50a	0.10hi	2.60g	90.12g
″ x sorghum	0.00c	0.00k	0.00i	0.00i	114.16g
″ x sole	37.50ac	41.87ef	0.87fg	2.30gh	138.72fg
Std error of the mean	21.98	13.97	0.29	3.35	49.32

Table 4 shows that infestation by the stem borer was lower in the 2:1 intercrop pattern than in the 1:1 or 3:1 patterns. Damage was significantly higher in intercrop pattern 1:1 than in the other patterns in 1997. In 1998, mean number of holes/ stem was significantly higher in the 2:1 than in 3:1 pattern. Tunnel length and number of holes were moderately positively correlated in 1997 (r = 0.79) but highly correlated in 1998 (r = 0.98). Grain yields were significantly higher in the 1:0 and 2:1 patterns in 1998 but in 1997, grain yield was significantly higher in the 1:0 pattern than in the other patterns. Grain yield in the 1:1 pattern was lowest in both years. Grain yields were highly negatively correlated with larval tunnel length in 1997 (r = -0.94) and also in 1998 (r = -0.93) and with numbers of emergence holes in 1997 (r = -0.90) and again in 1998 (r = -0.98). For the cropping systems, infestation was significantly higher in millet-cowpea than in millet –sorghum in 1997 while in 1998, both infestation and damage were significantly higher in millet-sorghum than in millet-cowpea system. Grain yields in millet-cowpea were significantly higher in 1997 and significantly lower in 1998 than in millet –sorghum.

Millet-sorghum cropping pattern 2:1 or 3:1 in 1997 and millet -cowpea cropping pattern 1:1 in 1998 did not suffer borer damage (Table 5). However, damage was significantly higher in the 1:1 millet-sorghum in 1997 and in the 2:1 or 1:1 millet-sorghum in 1998. Grain yields in sole millet pattern 1:0 in 1997 and 1998 or in the 2:1 millet-sorghum pattern in 1998 were significantly higher than in the other treatments.

Table 3. Effect of interaction of variety and cropping system on stem borer damage and grain yield of millet during the 1998 cropping season in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test).

Treatment	Mean percentage of stems bored/sample	Mean percentage of internodes bored/stem	Mean number of emergence holes/stem	Mean larval tunnel length (cm)/stem	Mean Grain yield (kg/ha)
Ex-borno x cowpea	70.00a	44.70a	10.57a	51.87a	277.15eh
″ x sorghum	66.67ab	20.30eg	3.17df	30.77bc	216.18gi
″ x sole	56.00ad	27.37be	6.40ad	29.67bc	344.53df
Mboderi x cowpea	23.33f	11.03gh	0.23f	2.20e	262.89fi
″ x sorghum	48.33be	31.70bd	5.10be	32.40bd	396.67be
″ x sole	24.33f	6.50h	1.33ef	2.90e	518.12ab
Gargasori x cowpea	50.00be	31.47bd	8.80ab	18.73be	168.22hi
″ x sorghum	50.00be	32.23bc	4.40cf	14.40ce	522.38a
″ x sole	43.67ce	20.37eg	2.60df	9.77de	448.21ad
Zongori x cowpea	60.00ac	34.80ab	6.40ad	16.73be	481.69ac
″ x sorghum	50.00be	16.83eh	3.23df	6.73de	547.85a
″ x sole	50.00be	16.03fh	3.53cf	15.00be	496.53ab
Wame x cowpea	33.33ef	35.97ab	3.90cf	8.67de	492.89ac
″ x sorghum	46.67ce	21.20dg	1.27ef	6.93de	370.79cf
″ x sole	49.83be	44.00a	7.57ac	24.33bd	326.29dg
GB8735 x cowpea	46.67ce	22.03cf	3.20df	11.47de	152.88i
″ x sorghum	40.00df	12.83fg	1.40ef	7.83de	291.29eh
″ x sole	50.00be	11.00gh	3.47cf	16.03be	188.84hi
Std error of the mean	8.99	3.71	31.47	6.00	59.50

Table 6 shows that in both 1997 and 1998, intercropping had no significant effect on grain damage or loss in grain yield due to the head miner. However, significantly higher damage and loss in grain yield were caused by the head miner in the 3:1 pattern than in the other patterns in 1998 (Table 7). The mean number of larvae/panicle was significantly higher in millet-cowpea than in millet-sorghum cropping system in 1998. The miners were also significantly higher in intercrop pattern 1:0 in 1997 and significantly lower in pattern 1:1 in 1998 than in the other cropping patterns. Grain yields were significantly higher in the 1:0 and 2:1 patterns in 1998 but in 1997, grain yield was significantly higher in the 1:0 pattern than in the other patterns. Grain yields in millet-cowpea were significantly higher in 1997 and significantly lower in 1998 than in millet –sorghum.

Table 4. Effects of cropping system and cropping pattern on stem borer damage and grain yield of millet in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test).

Treatment	Mean percentage of stems bored/sample	Mean percentage of internodes bored/stem	Mean number of emergence holes/stem	Mean larval tunnel length (cm)/stem	Mean grain yield (kg/ha)
1997					
Cropping system					
Millet-cowpea	59.22a	41.43a	1.38a	5.05a	178.46a
Millet-sorghum	27.80b	18.21b	1.88a	3.98a	168.58b
Std error of the mean	1.86	1.50	0.23	0.56	1.52
Cropping pattern					
3:1	28.50b	45.80a	1.15b	4.95b	129.55bc
2:1	27.80bc	17.60c	0.95bc	3.35c	184.04ab
1:1	93.38a	28.25b	4.15a	7.70a	90.75c
1:0	24.35c	27.63b	0.25d	2.05c	289.73a
Std error of the mean	1.57	1.40	0.29	0.59	46.95
Interaction	Sig.	Sig.	Sig.		Sig.
1998					
Cropping system					
Millet-cowpea	24.03b	16.32b	2.36b	8.93b	251.95b
Millet-sorghum	65.72a	43.94a	9.68a	38.29a	268.99a
Std error of the mean	1.91	2.48	1.40	3.23	15.44
Cropping pattern					
3:1	40.00a	28.35a	3.85b	15.47b	207.15b
2:1	45.00a	39.55a	9.02a	31.37a	285.62a
1:1	38.33a	26.25a	4.73ab	19.20a	204.56b
1:0	56.15a	26.37a	6.47ab	28.42a	344.56a
Std error of the mean	1.64	7.22	1.96	7.13	71.74
Interaction	Sig.	Sig.	Sig.	Sig.	Sig.

Discussion

Intercropping had different effects on the levels of infestation and damage to the different millet varieties by the insect pests. Susceptibility of millet to infestation and damage by insect pests has been reported to be inconsistent under natural field conditions (Ajayi 1985a; Ajayi 1990; Sastawa *et al*. 2002). Significantly higher borer tunnelling was sustained by Mboderi in 1997 and by Ex-borno in 1998 than the other varieties when sown under the different cropping systems; borer tunnelling severely limits grain formation in millet (Harris 1962; Elemo and Ajayi 1989). However, grain yields were significantly lower in GB8735 in 1997 and in GB8735 or Ex-borno in 1998 than in the other varieties. The lower grain yields in Ex-borno in 1998 may have been a direct consequence of the higher borer tunnelling suffered by this variety, particularly when intercropped with cowpea (Table 3). On the other hand, GB8735 that sustained lower borer tunnelling in both 1997 and 1998 produced lower grain yields suggesting that the yield potential of this variety is low under the prevailing cropping systems of this agroecology. Unlike local varieties, improved varieties such as GB8735 require optimum growth conditions for the realization of their yield potential. Some local cultivars are , nevertheless, inherently low yielding (Nwasike 1988), and this may explain why, in 1997, grain yields were lower in Gargasori inspite of the fact that it sustained only lower tunnelling from the stem borer and no damage from the head miner (Table 5). In contrast, Zongori grown under identical cropping systems produced significantly higher grain yields than the other varieties despite sustaining moderate borer tunnelling and miner damage (Tables1and 6) suggesting that this variety tolerated the insect pests more than the other varieties and also has high yield potential. However, grain yields were consistently higher in both sole and intercropped Zongori only in 1998 (Table 3). The reason for this may not be readily explained, but it is already known that water availability is one of the most limiting constraints to productivity in millet-based systems in Nigeria, especially under drier conditions (Grema and Hess 1994; Ajayi *et al.* 1998); 1997 had low and poorly distributed rainfall (514.6 mm in 41 days) than 1998 (with high and fairly distributed rainfall of 665.5mm in 61 days). It appears that optimum grain yield of Zongori under intercropping would possibly be realised only in years of fairly high rainfall. Yield advantages in intercrops have been partly linked to differences in water use efficiencies and active growth periods between associated crops in the intercrops (Steiner 1984).This phenomenon also may partly explain why grain yields in millet-cowpea intercrop were significantly higher in 1997 and significantly lower in 1998 than in millet-sorghum (Tables 3 and 6). Under low rainfall conditions of 1997, the deep roots of cowpea may have been advantageous in extracting water and nutrients from deeper soil zones for the benefit of millet more than the shallow roots of sorghum. In contrast, the active growth and demand periods of millet occur earlier than that of sorghum so that under wetter conditions in 1998, this temporal difference in millet-sorghum intercrop probably determined yield advantage more than the spatial difference (rooting pattern) in millet-cowpea intercrop. Temporal differences could be much more important than spatial differences in determining yield advantages in intercrops (Steiner 1984). The results imply that it is important to combine crop plants that will compliment each other in their demands and reduce interference, especially under drier conditions. It is already known that plants under stress or that have reduced vigour suffer disproportionately more from insect herbivores (Hodkison and Hughes 1982).

Sole millet sustained significantly lower borer tunnelling and produced higher grain yields than millet-sorghum or millet-cowpea intercrop systems and patterns in 1997 (Tables 1and 4). Conversely, more head miners infested sole millet than millet intercrops also in 1997 (Tables 6 and 7). Intercropping is known to reduce colonization of crops by some insect pests (Southwood and Way 1970; Way 1977; Lawani 1982; Steiner 1984; Mohammed and Teri 1989; Ajayi 1990; Swithri and Alexander 1995). However, in the intercrops, numerically higher miner infestation and damage occurred in millet-cowpea than in millet-sorghum in both 1997 and 1998 (Table 6) suggesting perhaps that sorghum interferes more than cowpea with the ability of the miners in locating their millet host. In contrast, millet-sorghum sustained higher levels of borer tunnelling than millet-cowpea in both 1997 and 1998 (Table 5); borer infestation may be higher if millet is intercropped with known hosts of *C. ignefusalis* than when millet is intercropped with non-hosts (Adesiyun 1983; Elemo and Ajayi 1989; Nwanze 1997). Smith, (1970) reported that component crops could be sources and causes of attack of the major crop especially in drier areas where there is an unstable equilibrium between the pest and their natural enemies. Nevertheless, the results are in agreement with those of other workers, that the type of component crop in the mixture affects the dynamics of and the potential damage that can be caused by insect pests in millet-based systems (Bhatnagar and Davies 1981; Bhatnagar 1987).

Table 5. Effect of interaction of cropping system and cropping pattern on stem borer damage and grain yield of millet in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test).

Treatment	Mean percentage of stems bored/sample	Mean percentage of internodes bored/stem	Mean number of emergence holes/stem	Mean larval tunnel length (cm)/stem	Mean grain yield (kg/ha)
		1997			
Millet-cowpea x 3:1	57.00c	91.60a	2.30b	9.90b	120.24d
″ x 2:1	55.60c	35.20c	1.90b	6.70c	194.37b
″ x 1:1	99.27a	11.10d	1.00bc	1.50d	109.48de
″ x 1:0	25.00d	28.83c	0.30c	2.10d	289.73a
Millet-sorghum x 3:1	0.00e	0.00e	0.00c	0.00d	138.85cd
″ x 2:1	0.00e	0.00e	0.00c	0.00d	173.71bc
″ x 1:1	87.50b	45.40b	7.30a	13.90a	72.02e
″ x 1:0	23.70d	27.43c	0.20c	2.00d	289.73a
Std error of the mean	3.92	3.75	0.94	1.09	16.57
		1998			
Millet-cowpea x 3:1	30.00c	30.40bc	2.50b	5.27c	222.89c
″ x 2:1	10.00d	8.53cd	0.43b	2.47c	257.09bc
″ x 1:1	0.00d	0.00d	0.00b	0.00c	183.26bc
″ x 1:0	56.10b	26.33b-d	6.50b	28.00bc	334.56a
Millet-sorghum x 3:1	50.00b	26.30b-d	5.20b	25.67bc	191.41c
″ x 2:1	80.00a	70.51a	17.60a	60.27a	314.14ab
″ x 1:1	76.67a	52.50ab	9.47ab	38.40ab	225.87c
″ x 1:0	56.20b	26.40b-d	6.43b	28.83bc	344.56a
Std error of the mean	3.21	8.77	3.16	8.60	21.34

The relatively higher number of miners in intercrop pattern 3:1 or sole crop pattern 1:0 than in intercrop pattern 1:1 in both 1997 and 1998 was probably due to the ease of colonization of millet panicles by miners since there were fewer (3:1) or no (1:0) stands of cowpea or sorghum to interfere with dispersal of head miners. It is known that crop growth patterns and plant size alter availability of host plants to insect pests and that increased vegetational diversity maintains lower insect pest population (Hodkison and Hughes 1982). Clearly, crop diversity was more in 1:1than in 3:1 or 1:0 cropping pattern and this may have been responsible for the differences in infestation levels between these intercrop patterns. A diverse polyculture of crop

Table 6. Effects of variety and cropping system on damage by *Heliocheilus albipunctella* and grain yield of millet in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test).

Treatment	Mean number of larvae/panicle	Mean percentage of panicles damaged+	Mean percentage grain loss	Mean grain yield (kg ha^{-1})
		1997		
Varieties				
Ex-borno	1.03a	1.65a	1.68a	279.69b
Mboderi	1.01b	1.37ab	1.44ab	293.34b
Gargasori	1.00b	1.00b	1.00b	208.71c
Zongori	1.02ab	1.29ab	1.30ab	353.74a
Wame	1.01b	1.51ab	1.53a	291.12b
GB8735	1.01b	1.15ab	1.19ab	114.33d
Std error of the mean	0.01	0.24	0.24	20.82
Cropping systems				
Millet-cowpea	1.01a	1.30a	1.33a	230.29b
Millet-sorghum	1.01a	1.36a	1.39a	144.14c
Sole millet	1.02a	1.32a	1.35a	396.04a
Std error of the mean	0.01	0.15	0.24	10.81
Interaction	S	NS	NS	NS
		1998		
Varieties				
Ex-borno	1.01b	1.51a	1.51a	279.29c
Mboderi	1.04a	2.00a	1.92a	392.56b
Gargasori	1.01b	1.26a	1.24a	379.60b
Zongori	1.03a	1.55a	1.59a	508.42a
Wame	1.01b	1.17a	1.18a	396.64b
GB8735	1.04a	2.01a	2.31a	211.0c
Std error of the mean	0.01	0.43	0.52	39.87
Cropping systems				
Millet-cowpea	1.02a	1.82a	1.86a	305.94b
Millet-sorghum	1.02a	1.34a	1.30a	390.73a
Sole millet	1.02a	1.58a	1.71a	387.09a
Std error of the mean	0.01	0.26	0.28	35.04
Interaction	NS	NS	NS	S

+Percentage of total adjusted length (TAL).

Table 7. Effects of cropping system and cropping pattern on damage by Heliocheilus albipunctella and grain yield of millet in Northeastern Nigeria. (Means followed by the same letters in a column are not significantly different at the 5% level of probability according to Duncan's Multiple Range Test)

Treatment	Mean number of beetles/panicle	Mean percentage of panicles damaged+	Mean percentage grain loss	Mean grain yield (kg ha^{-1})
		1997		
Cropping system				
Millet-cowpea	1.03a	1.92a	2.03a	178.46a
Millet-sorghum	1.02a	1.80	1.85a	168.58b
Std error of the mean	0.01	0.13	0.08	1.52
Cropping pattern				
3:1	1.02b	2.06a	2.16a	129.55bc
2:1	1.01b	1.73a	1.86a	184.04ab
1:1	1.02b	1.85a	1.95a	90.75
1:0	1.05a	1.82a	1.80a	289.75a
SE±	0.02	0.66	0.75	16.95
Interaction	NS	NS	NS	NS
		1998		
Cropping system				
Millet-cowpea	1,03a	2.07a	2.06a	251.95b
Millet-sorghum	1.01b	1.85a	1.95a	268.99a
SE±	0.01	0.32	0.35	15.44
Cropping pattern				
3:1	1.03a	2.52a	2.60a	207.15b
2:1	1.02ab	1.84b	1.96b	285.62a
1:1	1.01b	1.57b	1.63b	204.56b
1:0	1.02ab	1.94b	1.85b	344.56a
SE±	0.01	0.22	0.24	71.74
Interaction	NS	NS	NS	NS

+Percentage of total adjusted length (TAL).

systems, in contrast to simplified systems, provides more niches for crop pests but increases the severity of the systems to the pests by making the pests to spend more time and dissipate more energy in finding their hosts and by exposing them to increased predation (Van Emdem and Williams 1974; Way 1976); natural enemies are known to transfer from cowpea to millet in a millet- cowpea intercrop and reduce insect pests in millet fields (Bhatnagar 1987; Boire *et al.* 1998). The significantly lower grain yields in the 3:1 pattern in 1998 may be due to the significantly higher damage caused by the head miner in this pattern (Table 7). On the other hand, grain yields were low in pattern 1:1 also in 1998 and this may not be attributed to pest damage since pest damage was low. However, the implication is that the 1:1 intercrop pattern may not be suitable for improving millet yields in this agroecology despite the fact that mobility by insect pests may be more restricted in this pattern than in the other patterns. Grain yields were relatively higher in intercrop pattern 2:1 than 3:1 or 1:1 in both 1997 and 1998 (Tables 4 and 7) suggesting that this pattern may offer better yield stability to farmers than the 3:1 and 1:1 patterns in this agroecological zone. The relatively higher grain yields in sole millet pattern 1:0 in both 1997 and 1998 may be attributed entirely to the higher plant population in this pattern.

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