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Annual Report 1990

International Crops Research Institute for the Semi-Arid Tropics

1991

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ICRISAT

International Crops Research Institute for the Semi-Arid Tropics
ICRISAT Sahelian Center, B.P. 12404, Niamey, Niger

1991

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Cover: Aeroplane cabin view of ICRISAT Sahelian Center and research farm with the River Niger in background. (Photo by J. Brouwer).

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Introduction

The 1990 season at the ICRISAT Sahelian Center (ISC) was characterized by below-average rainfall, as were many other parts of West Africa. In Nigeria, sowing was delayed until July; in northern Mali, although the onset of rains was normal, there were subsequent dry spells, early insect attacks, and sandstorms. Nevertheless, research results are encouraging.

In Mali, the construction of the research center at Samanko was completed and the buildings were taken over from the contractor on 15 Oct 1990. All the electrical, airconditioning, and plumbing installations were checked by ICRISAT Center and ISC engineers. The regional West African Sorghum Improvement Program (WASIP/Mali) is jointly staffed by four French scientists from the Centre de coopération internationale en recherche agronomique pour le développement/Institut de recherches agronomiques tropicales et des cultures vivrières (CIRAD/IRAT) and sorghum scientists from ICRISAT, working as a consolidated team. The ICRISAT/Mali Bilateral Program, which works under the auspices of the Institut d'économie rurale (IER), will terminate in May 1991. This two-man team–again with generous funding from USAID–has contributed much to the development of the national research program of Mali.

In Nigeria, the sorghum improvement program (WASIP/Nigeria) has continued to develop the Bagauda station and completed the laboratories at Kadawa, which are shared with national scientists from the Institute of Agricultural Research (IAR). Following the posting of cowpea scientists from the International Institute for Tropical Agriculture (IITA) to Kano, we have developed joint programs with our respective mandate crops, mainly in the field of physiology and cropping systems. We have allocated land to IITA at Kadawa and Bagauda, and IITA, in turn, has provided us land at the Mingibir station, where they work with IAR. ICRISAT scientists attend the Cropping Scheme Programs of IAR and participate in joint trials. We also collaborate with the Lake Chad Research Institute (LCRI) on pearl millet research, and on dry-season sorghum grown in Bornu and Gongola states.

High-yielding sorghum hybrids and varieties developed by the team are being widely tested in West Africa. There is close collaboration with commercial organizations on the food and industrial uses of sorghum, an area in which we have also collaborated with the University of Ibadan and two Scottish research groups, the Scottish Crop Research Institute and the Heriot-Watt University. Training courses on sorghum hybrid seed production were again held in Kano, and in 1991, we plan to extend this course to other countries in West Africa in collaboration with Semi-Arid Food Grain Research and Development (SAFGRAD).

At the ICRISAT Sahelian Center, two greenhouses have been erected and commissioned, and various developments have been made. We continue to work with scientists from research centers of the Consultative Group on International Agricultural Research (CGIAR) as well as from other centers. The International Livestock Centre for Africa (ILCA) now has three scientists at ISC, and the International Board for Plant Genetic Resources (IBPGR) and the International Food Policy Research Institute (IFPRI), one each. We also have cooperative projects with the International Fertilizer Development Center (IFDC), the Institut français de recherche scientifique pour le développement en coopération (ORSTOM), the University of Wageningen (The Netherlands), and the University of Höhenheim (Germany). The post of the IITA cowpea breeder/agronomist has been transferred to the Southern African Development Coordination Conference (SADCC) region, but it is anticipated that a postdoctoral student will continue the program in 1991. It is also hoped that a scientist from the International Council for Research in Agroforestry (ICRAF) will be posted to ISC in 1991 to work with the agroforester on tree breeding and genetics.

Two important workshops were held in Niamey during early 1991. The first, in February, on "Soil Water Balance in the Sudano-Sahelian Zone," was jointly sponsored by ICRISAT, the Institute of Hydrology, and the Overseas Development Administration (ODA) of the UK, the World Meteorological Organization (WMO), and the International Association of Hydrological Sciences. All the papers were edited and published before the workshop commenced. The second workshop, the "Regional Workshop on *Faidherbia albida*," held in April 1991, covered the past and present role of *F. albida* in the West African semi-arid tropics and suggestions for preserving and extending the species. Jointly sponsored by ICRISAT, the Institut de recherche en biologie et écologie tropicale (IRBET), the Institut sénégalais de recherches agricoles (ISRA), the Institut national de recherches agronomiques du Niger (INRAN), and ICRAF, this workshop attracted a wide audience from Africa and other continents.

Following the decision to change the format of the Institute's Annual Report to make it shorter, and publish it under the title "ICRISAT Report 1990", this report from West Africa covers in greater detail the research carried out at ISC during the rainy season of 1990 and other events up to April-May of 1991.

R.W. Gibbons
Executive Director, West African Programs
and Director, ICRISAT Sahelian Center

ICRISAT Sahelian Center

ICRISAT Sahelian Center's Objectives

The ISC's objectives are an extension of ICRISAT's mandate:

1. To serve as a world center for the improvement of grain yield and quality of sorghum, millet, chickpea, pigeonpea, and groundnut and to act as a world repository for the genetic resources of these crops.

2. To develop improved farming systems that will help to increase and stabilize agricultural production through more effective use of natural and human resources in the seasonally dry semi-arid tropics.

3. To identify constraints to agricultural development in the semi-arid tropics and evaluate means of alleviating them through technological and institutional changes.

4. To assist in the development and transfer of technology to the farmer through cooperation with national and regional research programs, and by sponsoring workshops and conferences, operating training programs, and assisting extension activities.

Agroclimatic Environment

Introduction. The ICRISAT Sahelian Center at Sadoré is our principal research base for millet and groundnut, and for resource management associated with these crops in the Sahelian Zone of West Africa. Sadoré is located at 13°N, 2°E, near the town of Say, 45 km south of Niamey, Niger. The 500-ha experimental farm is characterized by reddish-colored, friable, sandy soils with low inherent fertility and low organic matter.

Seasons. The Sadoré area has a 4-month rainy season (June to September) and a long dry season extending from October through May. The average annual rainfall (560 mm at Niamey) is irregular and normally comes in the form of convective storms. The growing season is short (about 94 days), during which periodic droughts are not uncommon. During the dry season harmattan winds blow, bearing dust from the north and east. The average annual temperature is 29°C.

Crops. The main crop grown in the Sadoré area is early-maturing millet (90-100 days). It is sown with the first rains towards the end of May or early June, and at Sadoré an irrigated off-season nursery is used from January to April to increase seed availability and advance generations of breeding material. Intercropping millet with cowpea is common among local farmers. Cowpea is normally sown between the millet rows 2-3 weeks after the millet emerges, by which time rainfall occurs more frequently.

Weather. Monthly temperature and rainfall data for ISC, Sadoré during 1990 are shown in Figure 1. Mean maximum air temperatures from May to December were above the long-term average maximum. Total rainfall during 1990 (399 mm) was 27% below the long-term average (560 mm), with July, August, and September recording below-average rainfall. August rainfall in particular was only half the long-term average. However, rains early in the season were above average. The total rainfall for May of 77.1 mm was well above the long-term average of 34.4 mm, and these rains were received on 23, 29, and 30 May. These early rains in May enabled good crop establishment. Although the rainfall was below-average, rains were fairly well distributed through the rainy season. Average grain yields on the ISC station ranged from 1.0-1.5 t ha^{-1} for millet, and 1.0-1.5 t ha^{-1} for groundnut pods. Average yields for sole cowpea ranged from 0.6-1.0 t ha^{-1} for seed and 1.0-2.0 t ha^{-1} for hay.

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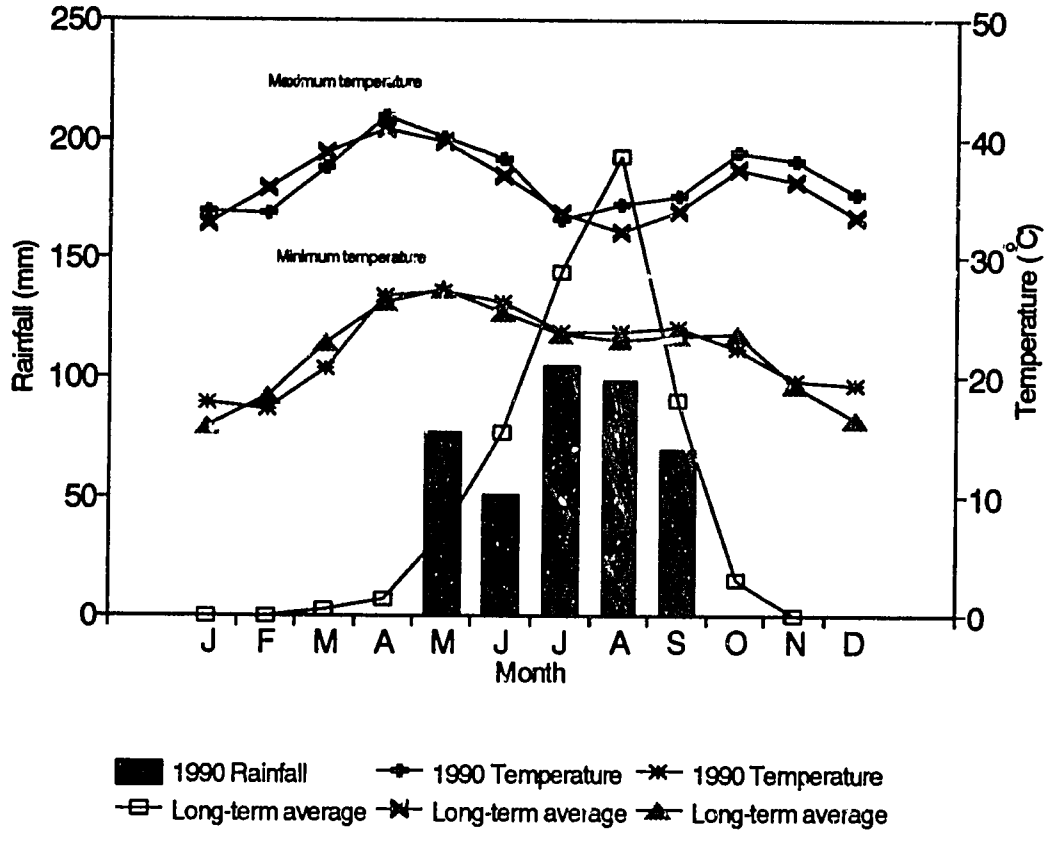

Figure 1. Monthly mean maximum and minimum air temperatures and monthly total rainfall in 1990, compared with long-term averages, Niamey, Niger.

Pearl Millet Improvement Program

Abiotic Stresses

Nutrient × Genotype Interactions

We analyzed the determination of yield of five millet genotypes at three fertility levels (LF = low fertility – no added fertilizer, MF = medium fertility – 23 nitrogen (N) + 23 phosphorus (P) , and HF = high fertility – 46 N + 40 P) to understand the mechanism of yield formation in improved varieties and a landrace.

Grain and stover yields were significantly different among the genotypes (P <0.01) and fertility levels (P <0.001) and there was a significant genotype × fertility interaction (P <0.05) (Table 1). Crop growth rate (CGR), grain growth rate (GGR), and partitioning (p = GGR/CGR) showed significant genotypic differences (P <0.001), while fertility affected only CGR and GGR, showing the conservative but dominantly genetic nature of p.

The local Sadoré landrace had the lowest p (approximately half that of the improved variety ICMV-IS 85321), but with low fertility had the highest growth rate. It is clear that breeding efforts to increase grain yield per se have increased p, but the CGR component of yield determination has been neglected in the breeding effort. In Sahelian agropastoral systems, where fodder has high value, the higher CGR of this landrace resulted in a product that has been neglected in the selection process.

Table 1. Grain yield, crop growth rate, grain growth rate, and partitioning of five millet varieties in low and high fertility treatments, ISC, Sadoré, rainy season 1990.

	Grain yield (kg ha^{-1})		Crop growth rate (kg ha^{-1} •Cd^{-1})		Grain growth rate (kg ha^{-1} •Cd^{-1})		Partitioning	
Variety	LF[1]	HF	LF	HF	LF	HF	LF	HF
IKMV 8201	261	746	0.42	1.04	0.25	0.69	0.60	0.63
ICMV-IS 85321	372	737	0.43	0.99	0.37	0.66	0.83	0.65
ICMV-IS 85327	297	554	0.45	0.94	0.28	0.52	0.60	0.55
P3 Kolo	299	985	0.47	1.16	0.27	0.90	0.57	0.76
Sadoré Local	195	736	0.54	1.52	0.19	0.65	0.37	0.42
SE (mean)	±62.6		±0.09		±0.07		±0.05	

1. LF = no added fertilizer; HF = 46 kg N + 17.5 kg P ha^{-1}.

Fertilizer input may provide a compensation in that it can also increase CGR, but it seems possible to have higher CGR at low levels of fertility and there is potential for gain in both fodder and grain.

Root Growth in Pearl Millet

We studied the growth of roots in some pearl millet lines in the rainy season 1990 to:

1. identify the existence of genetic variability in root growth that would contribute to pearl millet crop improvement; and

2. explore possible relationship of root length density (RLD) with known terminal drought response quantified as drought- response index (DRI) (ICRISAT Annual Report 1978/79, pp. 66-68; ICRISAT West African Programs Annual Report 1988, pp. 7-9). The DRI is often criticized as lacking any physiological basis.

Five millet genotypes with a range of DRI (–1.06 to 1.32) were sown in the rainy season with LF, MF, and HF. Roots were removed by soil coring whenever shoots were sampled, but only the root data at flowering are considered in this report.

There was significant genotypic variation (P <0.05) in RLD at flowering (Fig. 1); however, variation of RLD due to fertility, although apparent, was not significant. Most of the roots remained in the 0-50 cm soil zone and no variation in rooting depth was found.

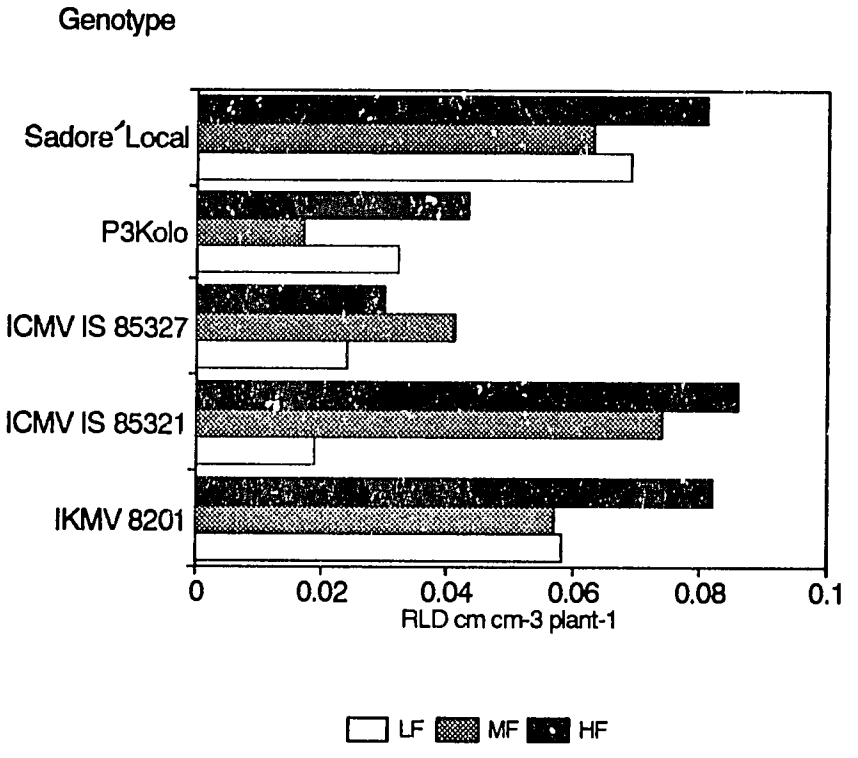

Figure 1. Root length density (RLD) measured at flowering in a few millet genotypes at three fertility levels, ISC, Sadoré, Niger, rainy season 1990.

Grain yields were not correlated with RLD in the MF and HF treatments, but were negatively correlated in the LF ($r = -0.81$, P <0.001). Mean DRI for the 1988, 1989, and 1990 summer seasons correlated well with RLD obtained from this experiment only for the HF treatment, (Fig. 2), i.e. at a fertility level similar to that at which DRI was estimated.

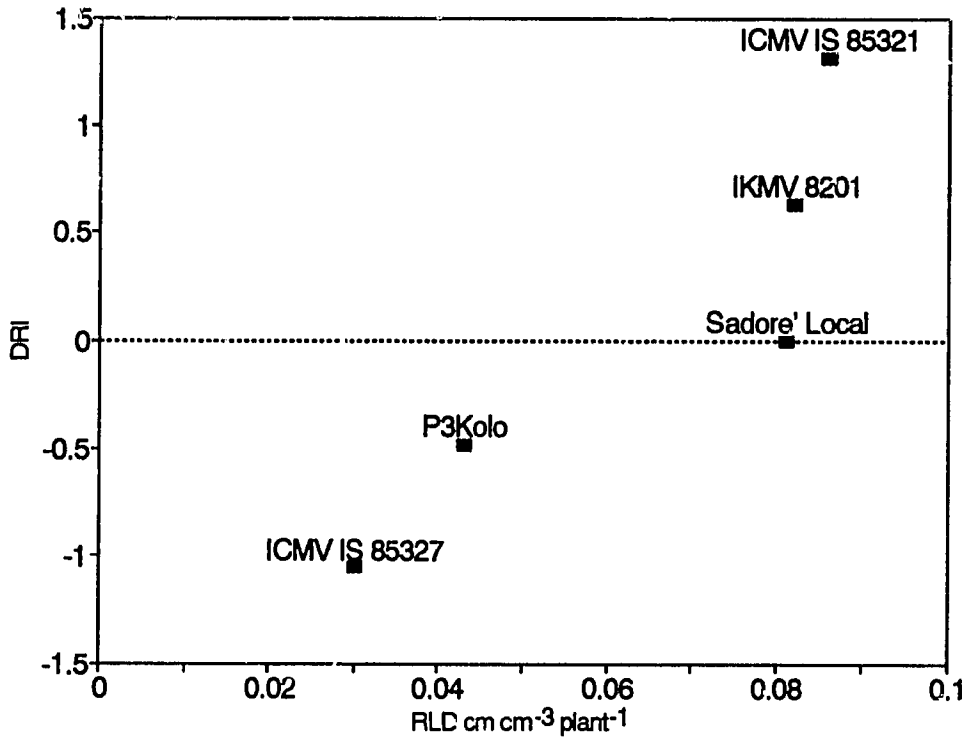

Figure 2. The relation between Drought Response Index (DRI) and RLD of 5 millet genotypes. DRI data are means of 1988, 1989, and 1990 summer drought screens and RLD are from high fertility treatment, rainy season 1990.

Biotic Stresses

Diseases

Downy Mildew

In 1990 we evaluated about 400 breeding materials at Bengou, including population derivatives and preliminary and advanced breeders' lines for downy mildew (*Sclerospora graminicola*) (DM). About 5% of the entries in the trials developed no DM and 24% showed an incidence of less than 5%. At Sadoré, 571 breeders' lines were evaluated during the off-season; of these 9% were disease-free and 15% showed less than 5% DM incidence.

Forty-five pot-grown entries of cultivated millet (collected by ORSTOM in Mali) were screened at Sadoré using artificial inoculation; 27 of these (54%) showed no DM symptoms and the remainder showed 17-67% infection. All plants of the susceptible control were infected.

Smut

Screening. One hundred and eleven entries from the millet breeding program were screened for resistance to smut (*Tolyposporium penicillariae*) at Bengou, using natural infection. Smut infection ranged from 3.5 to 25%, with only one entry (ICML-IS 82247) showing a high level of resistance (≤5% infection). Forty-five pot-grown entries of cultivated millet from Mali were screened at Sadoré, using artificial inoculation. Smut infection averaged 21% among

the test entries and was 64% for the susceptible control BJ 104. The only resistant entry was C-89-66 from Koporokeni-Na, with 1% infection.

Variability of *T. penicillariae*. Two millet varieties were evaluated for reaction to smut collections from West Africa at Bengou and Sadoré in 1989 and 1990. The smut samples were provided by collaborating pathology programs in Cameroon, Ghana, Guinée-Bissau, Mali, Nigeria, and Sénégal. Sporidia were produced on malt extract agar from all the smut collections for inoculation in the field, and for measuring colony size.

Millet hybrid BJ 104 is much more susceptible than the variety ICMS 8410, but both millets reacted similarly to the different smut isolates (Fig. 3). In 1989, quantitative differences were detected among the isolates at Bengou (Fig. 3). The isolates from Maroua (Cameroon) and Bambey (Sénégal) gave the highest smut ratings (47 and 44%, respectively) and the isolate from Sadoré, the lowest (27%). In 1990, differences in smut pathogenicity were evident only at Sadoré, where the isolate from Bawku-Manga (Ghana) gave the lowest smut rating (average of 29% on both varieties). The other isolates tested did not differ significantly, with smut ratings ranging from 39-46%. These data suggest that smut severity is influenced by both location and year of testing. We hope to initiate a regional smut observation nursery in 1991 to screen promising millet lines for smut resistance in various West African countries.

In 1989, an inverse correlation was seen between in vitro colony size and virulence in the field. This relationship did not hold true in 1990.

Ergot

Forty-five entries of cultivated millet from Mali were screened for reaction to ergot (*Claviceps fusiformis*) in pots at Sadoré, using artificial inoculation. Only one entry, C-89-38 from Kolokani, showed a high level of resistance. Average infection among the test entries was 19% and the smut-resistant entry, C-89-66, was most susceptible to ergot (60% infection).

Striga hermonthica

Screening for *Striga* Resistance

Forty-five millet cultivars from Mali were screened in pots for their reaction to *Striga hermonthica*. By 86 DAS, average infestation level per pot was 32 emerged *Striga* plants, with a maximum of 69 (±0.7) on C-89-54 from Jakamodi and C-89-55 from Monsonbougou and a minimum of 7 (±0.7) on C-89-64 from Garou. Thirteen entries did not differ significantly from the two highly susceptible lines. Fifteen entries did not differ significantly from the resistant line. The remaining 14 lines showed an intermediate number of emerged *S. hermonthica*.

Striga Management

Weeding. Over the past 5 years, we have run a trial examining the long-term effects of removing *Striga* from fields at four locations in Niger (Bengou, Sadoré, Chikal, and Samari). There was substantial variation in the data, but a combined analysis over years for Samari showed that the continued removal of *Striga* increased millet yield by 50% ($P<0.05$).

Fertilization. Two identical trials were conducted for the second year at Sadoré to continue investigation of the effect of N fertilizer application on *Striga* infestation. Four levels of urea (0, 30, 60, and 90 kg ha^{-1}) were applied. In one trial, reduction in *Striga* number was observed at the first count (69 DAS). In both trials, millet grain yield responded positively to N, regardless of *Striga* infestation level.

The lack of response of *Striga* infestation to N fertilization could be attributed to the low amounts applied (0, 14, 28, and 41 kg N ha^{-1}). Improved host vigor through N fertilization may help the host tolerate *Striga* attack, whereas *Striga* damage to the crop in nitrogen-poor soils may result in substantial yield loss.

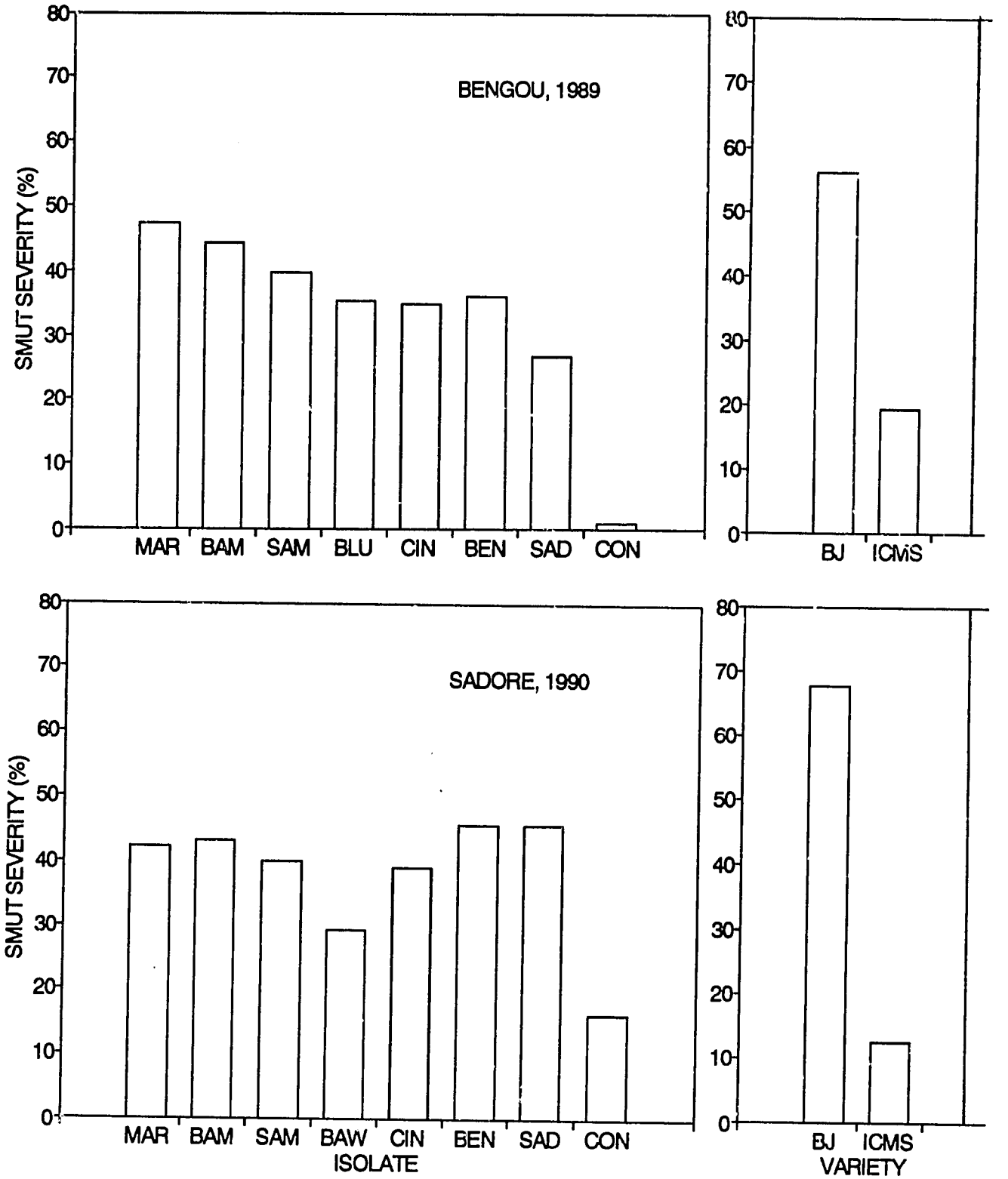

Figure 3. Smut severity on two millet cultivars tested for their reaction to eight isolates of *Tolyposporium penicilliariae* from West Africa. MAR = Maroua (Cameroon); BAM = Bambey (Sénégal); SAM = Samaru (Nigeria); BLU = Cacheu Blute (Guinée-Bissau); BAW = Bawku Manga (Ghana); CIN = Cinzana (Mali); BEN = Bengou (Niger); SAD = Sadoré (Niger); CON = Control (heads not inoculated). BJ = BJ 104; ICMS = ICMS 8410. Experiments conducted at Bengou and Sadoré during the 1989 and 1990 cropping seasons. Isolates from Cacheu Blute and Bawku-Manga were studied in only one year.

Variability of *S. hermonthica*

Our earlier work characterized the reproductive potential of millet *S. hermonthica* at Sadoré. However, as the parasite is highly variable, we expanded this work to include *S. hermonthica* from several widely separated regions of Niger.

Striga was collected from millet at Sadoré, Bengou, Birni N'Konni, and Maradi in late September. Percentage *Striga* infestation was estimated in four fields at each location (Table 2); while the height of 50 *Striga* plants was measured in only two fields. Fifteen mature plants with mature seed capsules were harvested, and additional measurements made in the laboratory. Table 3 shows the extent of variation in some morphological characteristics of the parasite. We plan to germinate seed harvested at the different locations in the laboratory to investigate the possible existence of different *Striga* strains.

Table 2. *Striga hermonthica* infestation on millet in different regions of Niger, September 1990.

Location	*S. hermonthica* infestation (%)[1]	SE (Mean)
Sadoré	71	±4
Bengou	64	±13
Birni N'Konni	48	±14
Maradi	74	±5

1. Average of 5 fields at Birni N'Konni, 4 fields at other locations.

Table 3. Some morphological characters of *Striga hermonthica* collected from different regions in Niger, September 1990.

Morphological characters	Location			
	Bengou	Sadoré	Birni N'Konni	Maradi
Plant height (cm)				
Max	60	59	46	41
Min	31	14	20	9
Mean	49	38	46	41
SE	±0.6	±1.0	±1.2	±1.3
n	200	100	100	100
Capsule no.plant^{-1}				
Max	232	5	55	±18
Min	95	15	41	±6
Mean	55	41	24	11
SE	±18	±6	±2	±11
n	12	13	23	24
Seed no. capsule^{-1}				
Max	1392	1012	818	1029
Min	443	161	1100	293
Mean	825	480	431	644
SE	±34	±30	±25	±56
n	44	41	64	19

Striga infestation was quite severe in Niger in 1990: 17-85% of millet hills were attacked in the fields we visited. The reproductive potential of *Striga* is phenomenal, with a single capsule producing up to 1400 tiny (0.34 × 0.18 mm) seeds and single plants producing up to 251 capsules. On average about 25 000 seeds were produced per *Striga* plant (Table 3).

Insect Pests

Millet Stem Borer

Identification and field-testing of the millet stem borer pheromone. Collaborative research was continued between ICRISAT and the Natural Resources Institute (NRI), UK on the pheromone of the millet stem borer, *Coniesta (=Haimbachia) ignefusalis*. We were able, with an improved rearing technique, to raise a large number of adults in excellent condition and obtain high yields of pheromone. Five components of the pheromone were identified (coded AGC1, AGC2, AGC3, AGC4, and AGC5 for the purpose of this report) and tested, in different combinations and mixture ratios, for their ability to attract males from late August 1990 to late October 1990.

Sticky traps were used for all experiments, set up in different field plots at Sadoré to compare pheromone components with virgin females. During the first of these tests, male stem borer moths were caught in both traps baited with either 5 or 10% AGC2 combined with AGC1 and traps baited with virgin females; blank traps caught no moths. This suggested that the binary mixture of 5% or 10% AGC2 in AGC1 was attractive. For the next step in this series of experiments, minor components were added to the AGC2/ACC1 binary mixture at different ratios and combinations. From this experiment, we found that:

- addition of AGC4 and AGC5 to the mixture decreased its attractiveness;
- AGC2 + AGC1 + AGC3 in a 7.5:100:6 ratio, dispensed from a polyethylene vial at an AGC1 loading rate of 0.5 mg, was at least as attractive as a virgin female to stem borer males.

Techniques for artificial infestation. We evaluated four techniques to enhance infestation levels of the millet stem borer, using dry stems infested in the previous season. Millet varieties CIVT, P3 Kolo, and Ex-Bornu were sown on 31 May 1990 in three-row blocks in eight cages (two for each technique). The techniques compared were:

1. individual stems positioned vertically between rows;
2. stems in bundles positioned vertically between rows;
3. stems in bundles positioned horizontally between rows; and
4. individual stems positioned horizontally between rows.

Infested stems were placed within cages twice, once at sowing and once again during vegetative growth. Fertilizer was applied at the rate of 40 kg P_2O_5 ha^{-1} before sowing, 13 kg N ha^{-1} at sowing, and 20 kg N ha^{-1} at 30, 45, and 60 days after sowing (DAS) Random plant samples were taken on three dates during the experiment, starting at 50 DAS. Five plants were sampled for each variety from each block within each cage, and the number of borers and the number of infested main stems and tillers recorded to compute percentage infested stems, tillers, and plants (Table 4). An analysis of variance showed statistically significant differences among the four techniques in infestation levels, but the interaction between technique and variety was not significant. The highest infestation was obtained when stems in bundles were placed vertically between rows.

These findings will be useful in screening for stem-borer resistance. Because there was no statistically significant interaction between technique and variety, either of the best two techniques can be recommended for use in places where artificially mass-reared borers are not available, to ensure infestation for screening purposes.

Our findings also have implications for pest management. Management of residue for fodder has a large impact on survival of the millet stem borer. The highest infestations were obtained when bundles of stems were used, regardless of their position. Therefore, to reduce infestations, fodder stored in bundles, stacks, or other aggregated storage systems should be used before the next rainy season.

Table 4. Evaluation of four techniques for artificially infesting millet with the stem borer, using infested previous season stems.[1]

Technique	Mean infestation level(%)[2]			Larvae in 5 Main stems[3]
	Plants	Main stems	Tillers	
Vertical single stems	16.0 (17.9)	10.8 (12.5)	8.7 (12.3)	1.0 (0.4)
Vertical bundles	57.9 (49.4)	49.3 (41.3)	30.6 (31.5)	13.0 (1.9)
Horizontal single stems	50.5 (43.6)	42.6 (37.4)	29.3 (30.4)	14.6 (1.8)
Horizontal bundles	34.1 (32.3)	23.3 (24.5)	14.4 (19.9)	2.9 (1.0)
SE (mean)	(±6.2)	(±3.7)	(±3.5)	(±0.3)
Mean	39.6 (35.8)	31.5 (28.9)	20.8 (23.5)	7.9 (1.3)
CV (%)	(27.6)	(28.0)	(36.3)	(49.8)

1. Split-plot experimental design with 2 replications (cages) of technique as the main plot and variety as subplot. Millet varieties used were CIVT, P3 Kolo, and Ex-Bornu replicated within cages three times.
2. Figures in parentheses are arc sine transformed values.
3. Figures in parentheses are log(y+1) transformed values.

Migration of Millet Head Caterpillar to Soil

In 1990 we studied the movement of the millet head caterpillar (*Heliocheilus albipunctella*) prior to its pupation in a plot sown with millet variety 3/4HK on 31 May 1990, at Sadoré. Normal cultural practices were used, and when the millet was at the milk stage, heads were examined and traps (supported by T-shaped metal standards) installed on heads infested by the caterpillar. The bottom of each trap was then covered with nondrying insect glue, so that larvae migrating from the millet head would be trapped as soon as they contacted the surface. Hourly observations of the larvae trapped and of the distances from the stem to where the larvae were trapped were recorded. Hourly temperature and humidity recordings were obtained from the Agroclimatology Unit.

The data show that larval migration is most important between midnight and 0600, with peak activity around 0400-0500 h (Fig. 4), coinciding with the period of lowest temperature and highest humidity. Further testing is needed to determine the role of temperature, humidity, and light on larval activity.

The distance from the peduncle to point of capture varied widely, indicating that migrating larvae do not move to the soil by crawling down the millet head and stem (Fig. 5). However, whether or not larvae use silken threads to let themselves down to the soil is not yet clear.

Plant Improvement

Stress Resistance Screening

As described in the section on biotic stresses, a large number of millet lines were screened for various stress factors. Table 5 shows the problem, trial location, numbers of lines evaluated, and the percentage found resistant.

Varietal Evaluation

Varietal evaluation results are considered separately for the Sudano-Sahelian Zone (Zone A) and the Northern Guinean Transition Zone (Zone B).

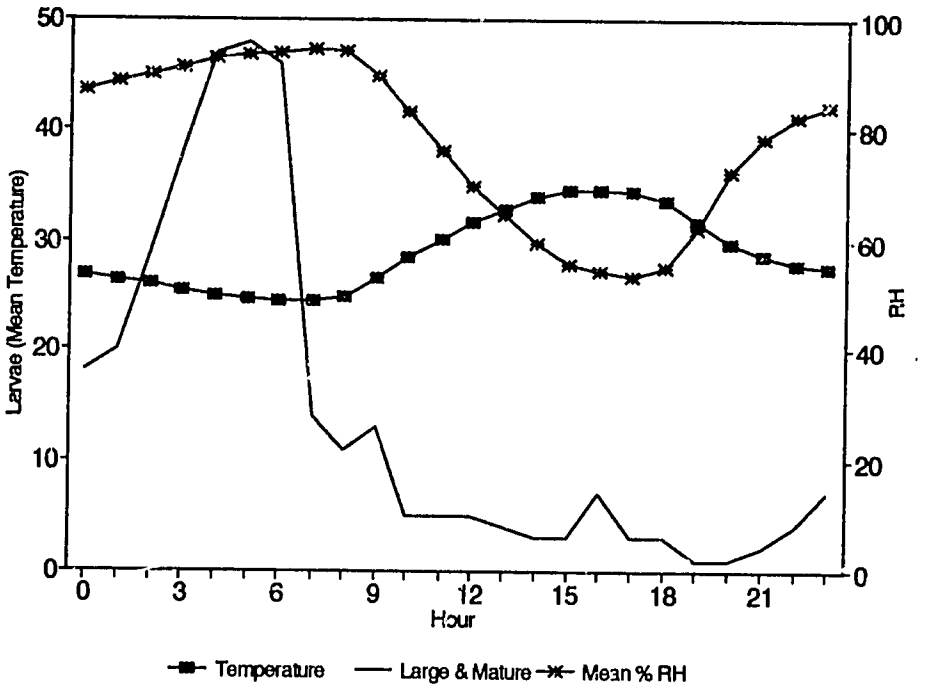

Figure 4. Movement of millet head caterpillar (*Heliocheilus albipunctella*) prior to pupation: larval migration in relation to time of day, temperature, and relative humidity (RH).

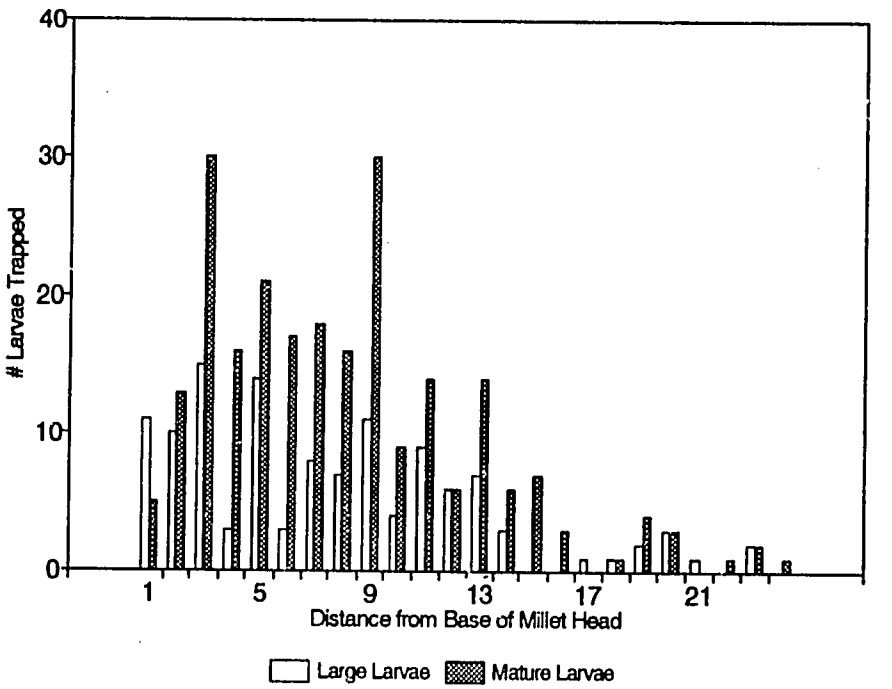

Figure 5. Movement of millet head caterpillar (*Heliocheilus albipunctella*) from millet head to soil prior to pupation: frequency of larvae trapped, by distance from base of peduncle.

Table 5. Summary of millet variety and germplasm screening by the ISC Pearl Millet Improvement Program in West Africa.[1]

Problem	No. of lines screened	Trial location	Lines found resistant (%)	Level of incidence
Downy mildew	400	Bengou	25	<5%
	571	Sadoré	15	<5%
	45	Sadoré (pots)	54	0%
	111	Bengou	1	<5%
Smut	45	Sadoré (pots)	2	<1%
Ergot	45	Sadoré (pots)	2	<5%
S. hermonthica	45	Sadoré (pots)	30	<20 pot^{-1}

1. The 45 lines tested in pot culture at Sadoré were germplasm lines collected by ORSTOM scientists.

Zone A Yield Trials

IMZAT 1989. The International Millet Zone A Trial (IMZAT 89) was conducted at 10 locations in 6 countries, and results were partially reported in 1989 (ICRISAT West African Programs Annual Report 1989, pp. 25-28). We now summarize results that came in too late to be included in the 1989 Report.

The 1989 IMZAT trial had 16 entries, including as controls a released improved variety and a local farmers' variety at each of five sites. The IAR, Nigeria, provided SE 2124 and SE Composite, and INRAN, Niger, contributed H 80-10 GR. Except at Cinzana in Mali, each of the best five entries ranked better than either control variety at all sites. Over all sites, the five most promising entries were: ICMV-IS 85327, ICMV-IS 89201, ITMV 8304, H 80-10 GR, and ICMV-IS 85321 (Table 6).

IMZAT 1990. In 1990 we again organized this West African regional millet yield trial. By the end of December 1990, data of the regional IMZAT 90 had been received from 6 of the 13 locations to which seed was sent (Table 7). At one site (Maiduguri; CV 40%) there were no significant differences. ICMV-IS 88305 (at all 5 locations), SOSAT-C 88 and ICMV-IS 88212 (at 4 locations), SOSAT-C 88, ICMV-IS 88224, and ICMV-IS 88312 (at 2 locations) were lines within the top five entries.

IAR-ICRISAT Joint Yield Trial 1990

A trial jointly conducted by IAR and ICRISAT tested 29 entries from which 10 (top yielding at Sadoré, Tara, and Kano) were chosen for further testing.

Data from the IAR-ICRISAT millet joint trial have been obtained from five of the seven locations to which seed was sent, but the variation at Samaru and Maiduguri were too high (CV's 40 and 37%) for useful comparison of varieties. Entries with promising yields at two of the three locations included: ICMV-IS 89201, ICMV-IS 90247, and ICMV-IS 88219, ICMV-IS 90251, and ICMV-IS 86330, and SVN-1. No entry ranked among the top ten at all three locations (Table 8).

Pearl Millet Advanced Varieties Trial (PMAVT 90)

The 1990 PMAVT was conducted with 11 test entries at Cinzana in Mali, Samaru in Nigeria, and Kolo, Sadoré and Tara in Niger (data from Cinzana have not yet been received). Over all sites, the most promising were ICMTCH-IS

Table 6. Mean grain yield of selected entries in the International Millet Zone A Trial (IMZAT 89) at five locations in Ghana, Bukina Faso, Niger, and Mali, rainy season, 1989.

Bawku (Ghana)		Kamboinsé (Burkina Faso)		Sadoré (Niger)		Kolo (Niger)		Cinzana (Mali)	
Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})
ICMV-IS 89201	0.94	ICMV-IS 85321	1.75	ITMV 8304	2.09	ICMV-IS 85327	0.83	H80-10-GR	2.15
ICMV-IS 88204	0.93	ICMV-IS 85327	1.64	ICMV-IS 86313	2.07	ITMV 8304	0.80	ICMV-IS 85327	1.92
ITMV 8304	0.89	SE 2124	1.63	ICMV-IS 85333	2.05	H80-10-GR	0.80	ICMV-IS 89201	1.83
SE Composite	0.88	ICML-IS 82271	1.60	ICMV-IS 89201	2.04	ICML-IS 82271	0.75	ITMV 8304	1.79
SE 2124	0.87	ICMV-IS 89201	1.56	ICMV-IS 85327	1.97	ICMV-IS 95321	0.73	ICMV-IS 85333	1.71
Control	0.65		0.55		1.82		0.70		1.77
SE	±0.10		±1.16		±0.17		±0.80		±0.17
Trial mean (16 entries)	0.78		1.40		1.80		0.68		1.64
CV (%)	25		22		19		37		22

Table 7. Mean grain yield of selected pearl millet entries in the International Millet Zone A Trial (IMZAT 90) at six locations in Burkina Faso, Niger, and Nigeria.

Kamboinsé (Burkina Faso)		Sadoré (Niger)		Kolo (Niger)	
Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})
ICMV-IS 88305	1.42	ICMV-IS 88219	1.98	ICMV-IS 88219	1.52
SOSAT-C 88	1.51	H 80 10 GR	1.79	SOSAP-C 88	1.50
ICMV-IS 88219	1.36	ICMV-IS 88305	1.68	ICMV-IS 88212	1.42
ICMV-IS 88212	1.56	ICMV-IS 88224	1.68	ICMV-IS 88305	1.38
ICMV-IS 87312	1.35	ICMV-IS 87312	1.62	SOSAT-C 88	1.34
Control	1.24		1.65		1.40
SE	±0.15		±0.20		±0.15
Trial mean (16 entries)	1.21		1.50		1.27
CV (%)	25		26		23

Kano (Nigeria)		Maiduguri (Nigeria)		Samaru (Nigeria)	
Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})
SOSAT-C 88	2.31	SOSAP-C 88	0.88	SOSAP-C 88	2.24
ICMV-IS 88305	2.28	ICMV-IS 88305	0.83	SOSAT-C 88	1.97
SE Composite	2.16	ICMV-IS 88210	0.78	SE 360	1.64
ICMV-IS 88224	2.12	ICMV-IS 86330	0.72	ICMV-IS 88305	1.63
ICMV-IS 88212	2.04	ICMV-IS 87312	0.63	ICMV-IS 88212	1.58
Control	2.16		0.66		1.75
SE	±0.08		±0.12		±0.89
Trial mean (16 entries)	1.90		0.60		1.47
CV (%)	9		40		26

89301 (a topcross hybrid variety), ICMV-IS 89305, and ICMV-IS 88271, which ranked among the top five at three locations (Table 9). At two locations, ICMTCH-IS 90301, ICMV-IS 88201, ICMV-IS 88298, and ICMV-IS 89301 ranked among the top five varieties.

Zone B (Transition Zone) Yield Trials

Millet varieties of different maturity groups were tested in six sets of multilocational yield trials. A full-season (115-130 days) variety advanced trial with eight entries was conducted at Samanko, Sotuba, and Katibougou, in Mali, in collaboration with IER. Five entries (ICMV-IS series) were reconstituted varieties obtained by recombining sets of S_1 selections from Malian germplasm accessions evaluated in previous years. IKMP 1, a recommended variety in Burkina Faso; M903, a recommended variety in Mali; and a local control were the other entries. Grain yield performance of the trial entries is given in Table 10. Grain yields were significantly different at each location. ICMV-IS 88102 and IKMP 1, which had shown stable good performance in previous trials (ICRISAT West African Programs Annual Report 1989, p. 22) did so again this year, with mean grain yield of 1.82 and 1.70 t ha^{-1}, respectively.

Table 8. Mean grain yield of selected pearl millet entries in the IAR-ICRISAT cooperative yield trial at five locations in Niger and Nigeria, rainy season 1990.

Sadoré (Niger)		Tara (Niger)		Samaru (Nigeria)		Maidugiri (Nigeria)		Kano (Nigeria)	
Entry	Yield (t ha^{-1})	Entry	Yield (t ha^{-1})	Entry	Yield (t ha^{-1})	Entry	Yield (t ha^{-1})	Entry	Yield (t ha^{-1})
ICMV-IS 85327	1.89	ICMV-IS 86330	2.87	SE 301	1.89	SYN 1	1.23	ICMV-IS 86330	1.66
ICMV-IS 88206	1.69	ICMV-IS 89201	2.71	SYN 1	1.89	ICMV-IS 88214	0.90	ICMV-IS 89201	1.54
ICMV-IS 90258	1.60	ICMV-IS 90232	2.63	SYN 2	1.74	ICMV-IS 88201	0.82	SYN 4	1.39
ICMV-IS 90246	1.57	ICMV-IS 88208	2.62	ICMV-IS 90258	1.70	ICMV-IS 88224	0.78	ICMV-IS 90247	1.38
ICMV-IS 88219	1.55	SE 300	2.62	SYN 6	1.63	ICMV-IS 90247	0.76	ICMV-IS 88224	1.37
ICMV-IS 90268	1.51	ICMV-IS 88219	2.59	SYN 3	1.59	SE 303	0.75	SYN 2	1.32
ICMV-IS 90247	1.50	ICMV-IS 90245	2.35	ICMV-IS 88224	1.56	SE 13	0.72	ICMV-IS 90251	1.30
ICMV-IS 88214	1.50	ICMV-IS 85333	2.33	ICMV-IS 90262	1.56	ICMV-IS 88219	0.64	SYN 3	1.30
ICMV-IS 88208	1.41	ICMV-IS 90269	2.32	ICMV-IS 89201	1.44	ICMV-IS 90262	0.64	ICMV-IS 90262	1.29
ICMV-IS 90251	1.37	ICMV-IS 88210(II)	2.27	ICMV-IS 82271	1.44	ICMV-IS 88210(II)	0.63	ICMV-IS 82298	1.25
Control	1.12	Control	2.31	Control	0.93	Control	0.51	Control	1.04
SE	±0.18		±0.34		±0.30		±0.13		±0.11
Trial mean (30 entries)	1.04		1.30		1.30		0.58		1.18
CV (%)	24		29		40		37		16

Table 9. Mean grain yield of selected pearl millet entries in the advanced variety trial at four locations in Niger and Nigeria, rainy season 1990.

Sadoré (Niger)		Kolo (Niger)		Tara (Niger)		Samaru (Nigeria)	
Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})	Entry	Mean yield (t ha^{-1})
ICMTCH-IS 89301	1.65	ICMV-IS 88201	2.02	ICMTCH-IS 89301	2.06	ICMV-IS 88271	1.20
ICMTCH-IS 90301	1.50	ICMV-IS 89305	2.01	ICMV-IS 89305	1.56	ICMV-IS 88298	1.09
ICMV-IS 89305	1.41	ICMV-IS 88298	1.86	ICMV-IS 89303	1.56	ICMTCH-IS 90301	1.08
ICMV-IS 88271	1.30	ICMTCH-IS 89301	1.67	ICMV-IS 88271	1.49	ICMV-IS 88271	1.03
ICMV-IS 88201	1.27	ICMV-IS 89301	1.64	ICMV-IS 89301	1.49	ICMV-IS 88211	1.02
Control							
CIVT	1.21	CIVT	1.64	CIVT	1.50	SE 2124	0.83
Sadoré Local	0.26	Kolo Local	1.52	Tara Local	0.29	Samaru Local	1.22
SE	±2.08				±4.47		
Trial mean (12 entries)	1.18		1.64		1.39		0.99
CV(%)	16				29		27

Table 10. Grain yield of full-season (115-130 days) pearl millet entries at three locations in Mali, rainy season 1990.[1]

Entry	Samanko	Sotuba	Katibougou	Mean yield (t ha^{-1})
ICMV-IS 89101	1.17 (5)	2.12 (2)	1.15 (5)	1.48
ICMV-IS 89104	1.04 (7)	1.63 (5)	1.42 (2)	1.36
ICMV-IS 89106	0.99 (8)	1.80 (4)	1.32 (4)	1.37
ICMV-IS 88102	2.14 (1)	1.95 (3)	1.38 (3)	1.82
ICMV-IS 88101	1.14 (6)	1.50 (6)	1.38 (3)	1.34
IKMP 1	1.37 (3)	2.31 (1)	1.42 (2)	1.70
Control				
M9D3	1.75 (2)	1.40 (7)	1.48 (1)	1.54
Local cultivar[2]	1.29 (4)	1.40 (7)	1.15 (5)	
SE	±0.17	±0.25	±0.14	
Trial mean	1.37	1.59	1.34	
CV(%)	28	32	23	

1. Randomized block design with 5 replications, net plot size 6 m^2; fertilizer at Samanko 17-17-17 complex at 100 kg ha^{-1}, other locations single superphosphate at 100 kg ha^{-1} and 50 kg ha^{-1} urea.
2. Samanko local at Samanko, Mangangolo at Sotuba, and Katibougou local at Katibougou.
3. Values in parentheses are ranks.

Another full-season (130-150 days) advanced variety trial with 12 entries was conducted at three locations in Mali and one in Burkina Faso. This included eight entries (ICMV-IS series) from the Transition Zone (TZ) program, entries Djiguifa, Magangolo, and M903 from IER, and the control. Grain yield performance of the selected entries is

given in Table 11. Entry ICMV-IS 88102 was again the stable top performer with mean grain yield of 2.16 t ha^{-1}. ICMV-IS 88102 was reconstituted in the 1987/88 postrainy season at Kamboinsé by recombining selected S_1 progenies from Malian germplasm accessions evaluated in previous years. It is a 130-day variety, suitable for the Southern Sudanian and Northern Guinean zones, for which no improved varieties are yet recommended in Burkina Faso; INERA, Burkina Faso, has plans to advance this variety to on-farm trials in the coming season. It will be proposed for IER national trials in Mali.

In the preliminary yield trials promising entries of 115-130 days maturity were RPL 209, RPL 732, ICMV-IS 89113, and ICMV-IS 89115.

Table 11. Grain yield of long-duration (130-150 days) pearl millet entries at four locations in Mali and Burkina Faso, rainy season 1990.

Entry	Samanko (Mali)	Sotuba (Mali)	Longorola (Mali)	Farako-ba (Burkina-Faso)	Mean yield (t ha^{-1})
ICMV-IS 88102	2.93 (2)[2]	2.65 (2)	1.55 (2)	1.51 (3)	2.16
ICMV-IS 88103	2.93 (2)	2.20 (9)	1.68 (1)	1.63 (2)	2.11
Magangolo	2.74 (3)	2.67 (1)	1.35 (3)	1.46 (4)	2.05
M9D3	2.61 (4)	2.54 (3)	1.68 (1)	1.21 (9)	2.01
Control					
Local cultivar[1]	2.13 (6)	2.53 (4)	1.33 (5)	0.87(12)	
SE	±0.19	±0.28	±0.19	±0.16	
Trial mean	2.23	2.19	1.32	1.29	
CV(%)	19	29	32	28	

1. Samanko local at Samanko, Mangangolo at Sotuba, and Sanko at Longorola.
2. Values in parentheses are ranks.

Population Improvement

Following IKMP 1 S_1 evaluation in the previous year (ICRISAT West African Programs Annual Report 1989, p. 24), 132 out of 760 S_1 progenies were selected. Four to six selfed plants from each of the selected progenies were harvested as S_2s and bulked; Original S_1 seeds of the selected progenies were grown in isolation during the second cycle of recombination to give IKMP 1 (C2); 97 had sufficient seeds for conducting replicated yield trials at more than one location. The 97 selected S_2 lines, IKMP 1, IKMP 1 (C2), and a control were grown in a trial in the 1990 season at Samanko and Cinzana in Mali, and Kamboinsé in Burkina Faso. Grain yield data are available for Samanko only, visual scores were made at other locations. A total of 17 S_2 progenies were selected for recombination. IKMP 1 and IKMP 1 (C2) were also included as entries in two other varietal trial sets conducted at different locations. Results from five trials showed the mean grain yield of IKMP 1 and IKMP 1 (C2) to be 1.86 and 2.08 t ha^{-1} respectively.

A total of 297 S_2 progenies selected from varietal composite IKM 85/86 RP 1 (ICRISAT West African Programs Annual Report 1989, p. 24) were evaluated at Samanko; 58 progenies of desirable maturity and height were selected for recombination. In addition, 30 progenies were selected for observation as individual lines after sib-multiplication.

Genetic Diversification

Thirty-seven F_1s out of 140 crosses, 96 F_2 progenies from 31 F_2 populations, and over 200 F_3-F_5 lines were selected for continued evaluation. Twenty-two highly promising advanced lines are being individually multiplied by sibbing for replicated trials and to supply to cooperators in national research programs.

Cooperation with National Programs

Supply of Breeding Materials

We provide improved millet breeding materials to the national agricultural research systems (NARS) through our collaborative nurseries, or in response to specific requests. These materials may be newly developed experimental varieties, parental lines, or pedigree progenies at various stages of inbreeding. In 1990, Nigeria and Ghana received and yield-tested 30 of ICRISAT's new experimental varieties; Niger, Burkina Faso, Mali, and Sénégal received 9 varieties; and Zimbabwe was supplied with 49 advanced breeding lines. New recipients of ISC's lines were Namibia, which was supplied with 91 advanced breeding lines and varieties, and Zaire, which received 9.

Evaluation and Screening of NARS Materials

A joint project between ICRISAT and the Ghana national program was initiated to improve the local Ghanaian millet variety, Manga. This variety has good yield potential but is highly susceptible to downy mildew. We are subjecting it to selection pressure in the DM nurseries at ISC to improve its resistance to DM.

Through regional multilocational trials, we have tested five new varieties from IAR, Nigeria, and three from INRAN, Niger.

The West and Central Africa Millet Research Network (WCAMRN)

The steering committee of the WCAMRN met 17-18 Sept 1990 at ISC, Niamey, to finalize a draft document of the network constitution, for presentation to the members at the meeting held on the 19th. Representatives from SAFGRAD, the Swiss Development Cooperation, the ICRISAT-Mali Bilateral Program, and the Coordinator of the West and Central Africa Sorghum Research Network (WCASRN) also attended the meeting.

The committee had previously designed a questionnaire which had been filled out by all 14 member NARS. Using this information the constraints to production were identified and prioritized; and based on the resources indicated the committee identified "Lead NARS" for each ecological zone. Sénégal, Niger, and Mali were designated for the Sahelian Zone; Burkina Faso and Nigeria for the Sudanian Zone; and Côte d'Ivoire and Burkina Faso for the Northern Guinean Zone.

The West African Regional Millet Workshop

The 1990 ICRISAT West African Regional Millet Workshop was held September 19-21 at ISC, Niamey, Niger Republic. A total of 55 participants representing all 14 millet programs of the WCAMRN, representatives of SAFGRAD, ICRISAT, USAID, the Swiss Development Cooperation, and the Coordinator of the WCASRN attended the workshop. Twelve NARS scientists presented papers on the current status of millet research in their countries, and several technical research papers were presented.

The workshop also familiarized participants with prevailing concepts and membership responsibilities in crop research networks. Accordingly, presentations outlining the basis, philosophies, and strategies of research networks, were presented by representatives of SAFGRAD, the Swiss Development Cooperation, the Coordinator of the WCASRN, and the ICRISAT-Mali Bilateral Program.

Groundnut Improvement Program

Introduction

Our research interest continued to focus on the major abiotic and biotic stress factors that limit groundnut production. These are: drought, leaf spots, aflatoxin contamination, peanut clump virus (PCV), varietal adaptability, crop growth variability, cropping systems, and plant nutrition. Our interaction with the External Program and Management Review team members helped us to reorient our future plans. Our collaboration with NARS was expanded to include Sénégal and Sierra Leone in addition to Bénin, Burkina Faso, Cameroon, Gambia, Ghana, Guinea, Niger, and Nigeria. The Second Regional Groundnut Meeting for West Africa held in Niamey in September 1990 offered us an excellent opportunity to follow up on the recommendations made during the first meeting and to review progress made in groundnut research in the region. Students from the region and other parts of the world carried out research work in our program.

Abiotic Stresses

Drought

Droughts are complex situations, during which crops may experience various combinations of water, heat, and nutrient stresses as a result of inadequate water supply, and may become vulnerable to diseases or pests. We planted a trial with 36 genotypes on 24 Jul 1990, about 1 month after the rains had established. One-half of the trial was irrigated through to maturity, and the other half was subjected to end-season drought.

Pod and haulm yields, shelling percentage, and 100-seed mass are presented in Table 1. Significant differences in yield were found between genotypes. Under the nonstressed conditions, genotypes ICGM 614 and ICGV 87185 gave the highest pod yields. These genotypes also had significantly higher crop growth rates, but had low partitioning. ICGM 614 haulm yields were also among the top three, with 28-206 and ICGV SM 85764.

Under end-season drought stress, yields were generally very low, but three categories of genotypes emerged: (1) Those that combined good pod and haulm yields; ICGV 85043 and ICGV 86024 were the only two in this group. (2) Those that could produce pods or haulms but not both; 796, ICGM 614, and ICGV SM 85764 were in this category. (3) Those that gave poor pod and haulm yields; ICGV MS 86051, ICGV SM 85002, ICGM 336, and ICGM 631 were in this group. These genotypes also had low crop and pod growth rates, 100 seed-mass, and shelling percentage (Table 1).

Plant Nutrition

In collaboration with the University of Höhenheim, Germany, we examined the effect of crop residues, chelates, and various applications of phosphorus (P) and molybdenum (Mo) on the performance of groundnut, using 14 treatments (see Table 2).

The treatments had a significant effect on plant height, and haulm and pod yields (Table 2). Treatment 2 (4 t ha^{-1} of crop residue) gave a pod yield as high as treatments 9, 10, and 12 (P and Mo). All the treatments except 3, 7, and 8 yielded more haulms than the control. Treatments 3 and 8 did not differ significantly from the control in plant height.

In collaboration with the University of Bonn, Germany, we examined the role of plant morphology in influencing the calcium (Ca) nutrition of pods. We evaluated the differences in Ca-uptake efficiency between two groundnut bunch types (28-206 and ICGMS 42) and two runner types (47-16 and M 13) at two Ca levels (0 and 400 mg kg^{-1}) in the pod zone. Soil moisture in the upper 10 cm soil layer measured gravimetrically under the plants, did not differ between bunch and runner types. Pod yields of the two runner types were in general higher than those of the bunch types. Mean pod yield from the four genotypes was 0.82 t ha^{-1} without Ca and 0.97 ±0.168 with Ca. Analysis of Ca in pods did not show any difference between genotypes or Ca treatments.

We also compared pop and pod distribution in a runner (47- 16) and a bunch (28-206) type of similar pod size. Runner types distributed more of their pods further away from the stem than bunch types. The percentage of pops was

Table 1. Performance of 36 late-sown drought resistant groundnut cultivars at ISC, 1990.[1]

Cultivar	Nonstressed				Stressed			
	Yield (t ha^{-1})		Shelling (%)	100-seed mass (g)	Yield (t ha^{-1})		Shelling (%)	100-seed mass (g)
	Haulms	Pods			Haulms	Pods		
ICGV-SM 86725	1.12(11)[2]	1.29(4)	67.27	58.25	0.45(16)	0.21(21)	41.25	42.50
ICGV-SM 83005	0.58(32)	0.68(34)	66.98	48.00	0.32(26)	0.13(29)	25.62	28.75
ICGV-SM 83011	0.76(26)	0.99(21)	66.74	49.00	0.39(22)	0.18(23)	29.62	28.75
ICG 85039	1.33(4)	1.17(12)	51.65	39.50	0.95(1)	0.30(13)	33.87	28.75
ICGV-SM 85043	0.95(18)	1.06(16)	64.67	40.00	0.57(8)	0.41(2)	47.12	30.25
ICGV-SM 86051	1.15(10)	1.04(17)	53.23	41.25	0.23(33)	0.12(31)	16.25	28.50
ICGV-SM 86052	1.27(6)	0.70(33)	30.07	41.25	0.71(4)	0.15(26)	15.25	20.00
ICGV-SM 85002	0.58(31)	0.73(31)	57.34	43.50	0.22(35)	0.06(35)	11.12	22.25
ICG-SM 85764	1.40(3)	1.08(14)	56.97	52.75	0.61(7)	0.17(24)	29.00	35.75
ICGM 197	1.06(14)	1.08(15)	60.07	37.50	0.50(11)	0.24(19)	34.50	28.75
ICGM 336	0.46(35)	0.71(32)	69.37	44.25	0.16(36)	0.10(33)	24.12	30.75
ICGM 614	1.42(1)	1.37(1)	62.31	67.25	0.50(13)	0.11(32)	23.12	37.25
ICGM 623	1.23(7)	1.02(18)	57.13	54.75	0.48(15)	0.09(34)	12.50	22.25
ICGM 631	0.84(22)	0.76(29)	56.58	41.00	0.25(32)	0.05(36)	9.62	13.75
ICGV 87156	0.72(27)	0.83(27)	50.61	43.50	0.43(19)	0.29(14)	32.62	33.75
ICGV 87157	0.77(25)	0.65(35)	54.34	41.25	0.34(24)	0.13(30)	23.25	31.25
ICGV 87160	0.83(23)	1.19(10)	52.13	32.75	0.49(14)	0.34(7)	36.12	25.75
ICGV 87185	1.17(8)	1.36(2)	52.92	34.50	0.45(17)	0.34(8)	37.37	26.75
ICGV 86024	1.00(15)	1.27(7)	59.38	48.00	0.79(3)	0.38(5)	43.00	36.75
ICGV 86548	0.68(28)	0.90(26)	53.77	49.75	0.28(30)	0.13(28)	23.62	29.25
ICG 1260	1.10(12)	1.00(19)	65.37	34.50	0.29(28)	0.15(27)	28.25	24.50
ICG 2140	0.88(21)	1.00(20)	63.86	39.00	0.52(10)	0.32(11)	54.12	32.50
ICG 2229	0.66(29)	0.73(30)	65.95	36.25	0.29(29)	0.27(15)	52.25	28.75
ICG 2371	1.09(13)	1.28(5)	65.07	46.50	0.65(5)	0.18(22)	23.75	25.75
ICG 8361	0.96(17)	1.21(8)	69.30	41.50	0.42(20)	0.35(6)	54.75	31.25
ICGV-SM 83701	1.29(5)	1.28(6)	65.70	46.00	0.82(2)	0.26(17)	44.50	35.50
ICG-SM 83709	0.65(30)	0.91(24)	73.84	41.25	0.41(21)	0.25(18)	43.50	31.75
ICGV-SM 86066	0.50(34)	0.82(28)	71.51	36.00	0.22(34)	0.31(12)	46.62	28.00
ICGV 68168	0.94(19)	1.14(13)	62.00	36.50	0.54(9)	0.40(3)	45.12	29.50
ICGV 87078	0.91(20)	0.98(22)	66.72	35.00	0.26(31)	0.22(20)	43.37	24.74
ICG 87086	0.98(16)	1.17(11)	61.56	40.00	0.44(18)	0.39(4)	45.37	29.50
ICGV 87087	1.16(9)	1.35(3)	61.37	42.00	0.50(12)	0.27(16)	38.25	28.50
Control								
55-437	0.40(36)	0.51(36)	66.51	30.25	0.34(23)	0.34(9)	57,87	24.00
28-206	1.41(2)	1.19(9)	65.91	36.00	0.62(6)	0.15(25)	31.25	24.25
TS-32-1	0.82(24)	0.93(23)	63.81	39.00	0.33(25)	0.33(10)	48.50	30.00
796	0.57(33)	0.91(25)	67.69	37.50	0.31(27)	0.47(1)	59.00	30.00
SE	±0.17	±0.17	±2.13	±1.77	±0.08	±0.06	±5.75	±3.75
Trial mean (16 entries)	0.94	1.012	61.11	42.36	0.45	0.24	35.15	28.88
CV (%)	35.58	29.32	6.86	8.25	37.62	47.74	32.60	25.76
Lattice efficiency (%)	112	108	120	<100	103	101	<100	<100

1. A 6 × 6 lattice with 4 replications; plot size 10.5 m^2.
2. Numbers in parentheses show ranking of each cultivar in the trial.

similar at all distances in the runner type. Ca analysis showed that the larger pods of the bunch type had a higher Ca (0.07% ± 0.013%) than those of the runner type (0.05%). The same trend was observed with the groundnut shells (0.13 and 0.11 ± 0.011% respectively).

We initiated a new trial in 1990 in which 20 groundnut genotypes of diverse origin were evaluated for their response to lime application. Lime treatments were 0, 7.5, and 12.5 t ha^{-1}. There was no significant interaction between lime and groundnut genotype at Sadoré and Tara.

Table 2. Effect of crop residue, chelate, phosphorus (P) and molybdenum (Mo) on groundnut cv 55-437 at ISC, rainy season 1990.[1]

Treatment	Plant height (cm)	Yield (t ha^{-1})	
		Haulms	Pods
1. Control	23	0.97	1.36
2. 4 t ha^{-1} crop residue (CR)	35	1.67	1.79
3. 80 kg ha^{-1} chelate (EDTA)	27	1.16	1.50
4. 4 t ha^{-1} CR + 16 kg ha^{-1} P (as SSP)	38	2.15	1.70
5. Chelate + 16 kg ha^{-1} P	34	1.49	1.65
6. 16 kg ha^{-1} P (foliar application)	35	1.53	1.54
7. 16 kg ha^{-1} P (placed below seeds)	33	1.33	1.49
8. 16 kg ha^{-1} P (broadcast)	28	1.33	1.36
9. 16 kg ha^{-1} P + 50 g ha^{-1} Mo[2]	36	1.98	1.75
10. 16 kg ha^{-1} P + 100 g ha^{-1} Mo	32	1.62	1.79
11. 16 kg ha^{-1} P + 200 g ha^{-1} Mo	30	1.53	1.70
12. 16 kg ha^{-1} P + 300 g ha^{-1} Mo	32	1.57	1.77
13. 16 kg ha^{-1} P + 400 g ha^{-1} Mo (foliar application)	39	2.21	1.68
14. 16 kg ha^{-1} P + 500 g ha^{-1} Mo (foliar application)	36	2.15	1.59
SE	±0.23	±0.134	±0.133
CV (%)	17	21	20

1. Randomized complete block design with 6 replications; plot size 36 m^2.
2. Mo applied as molybdenum oxide (MoO_3).

Intercropping

Using data from the intercropping studies in 1988 and 1989 (ICRISAT West African Programs Annual Report 1988, p. 41; 1989, p. 32), we computed trade ratios for the grain and fodder to assess the tolerance of groundnut cultivars to intercrop competition at Sadoré, Bengou, and Tara.

The following equation was used:

$$TR = X_i/(Y - Y_i)$$

where X_i = yield of crop 1 in the intercrop; Y = yield of crop 2 as a sole crop; Y_i = yield of crop 2 in the intercrop.

The trade ratio indicates the gain of one component relative to its competitive impact on the companion crop. With the data set available, it was possible to examine both the impact of millet at varying densities on a sole groundnut crop and the impact of groundnut varieties on the millet crop. In some treatments the intercrop yielded the same, or slightly (not significant) more than the sole crop, and for these no trade ratio was computed. Trade ratios have been computed from the point of view of both the introduction of groundnut into a sole crop of millet (Table 3) and the introduction of millet into a sole crop of groundnut (Table 4).

Generally, the introduction of any cultivar of groundnut into millet at any of these spacings substantially reduced the yield of both millet fodder and grain; however, this decrease was well compensated for by groundnut 1.5 to 4 times the amount of millet lost. When millet was introduced into a sole groundnut crop, the groundnut:millet trade ratios increased with increasing spacing between millet rows. The most profitable intercrop arrangement in terms of millet grain and straw yield per unit decrease in groundnut pod and haulm yield was 5 rows of groundnut:2 rows of millet at 1 × 3 m spacing. This trend was observed at all sites.

We continued a trial that was initiated in 1989 (ICRISAT West African Programs Annual Report 1989, p.33) to evaluate the performance of 12 groundnut cultivars both as sole crops and intercropped with pearl millet (cv CIVT) at Sadoré, and at INRAN stations Tara and Maradi. At Ina, in Bénin, the millet was replaced by maize. At Maradi and Ina, the crops were sown late, so no useful data were obtained for millet and maize. There were varietal differences in groundnut yields. At Ina and at Sadoré, cv 28-206 gave the highest pod yield (1.88 and 2.17 t ha^{-1}, respectively); at

Table 3. Effect of groundnut cultivar and millet crop density on groundnut:millet trade ratio.[1]

	Sadoré						Bengou			Tara		
	1988			1989			1988			1989		
Treat-ment[2]	Haulm/ straw	Pods/ grain	Total	Haulm/ straw	Pods/ grain	Total	Haulm/ straw	Pods/ grain	Total	Haulm/ straw	Pods/ grain	Total
1.	2.650	0.642	1.560	2.094	0.636	1.354	0.588	4.085	1.749	2.201	2.069	2.161
2.	1.345	0.339	0.838	3.667	0.846	2.000	0.877	2.612	1.623	1.800	2.333	1.929
3.	4.071	0.640	1.872	-[3]	4.500	-	0.731	2.235	1.583	2.400	-	5.500
4.	2.158	0.882	1.575	3.727	2.250	3.206	0.576	1.969	1.249	1.805	3.152	2.025
5.	1.764	0.571	1.247	-	6.500	27.50	0.337	1.490	0.953	2.279	-	3.266
6.	2.174	1.059	1.700	-	-	-	0.571	1.158	1.000	1.180	27.00	1.686
7.	2.804	1.259	2.018	1.641	0.710	1.229	0.635	2.461	1.463	2.423	1.899	2.248
8.	3.480	1.333	2.581	2.222	1.000	1.647	0.390	11.83	1.036	1.333	2.000	1.500
9.	3.529	1.118	2.324	4.750	1.250	3.000	0.463	-	10.33	1.386	1.714	1.466

1. Kg of groundnut gained per kg of millet sacrificed.
2. Treatment: 1 = Millet at 1 m × 1 m and groundnut cv 55-437 (or 28-206); 2 = Millet at 1 m × 2 m and 55-437 (or 28-206); 3 = Millet at 1 m × 3 m and 55-437 (or 28-206); 4 = Millet at 1 m × 1 m and TS 32-1 (or 47-16); 5 = Millet at 1 m × 2 m and TS 32-1 (or 47-16); 6 = Millet at 1 m × 3 m and TS 32-1 (or 47-16); 7 = Millet at 1 m × 1 m and ICGS(E) 11; 8 = Millet at 1 m × 2 m and ICGS(E) 11; 9 = Millet at 1 m × 3 m and ICGS(E) 11.
3. Introducing groundnut into millet did not decrease millet yield.

Table 4. Effect of millet crop density and groundnut cultivar on millet:groundnut trade ratio (millet introduced into a groundnut sole crop).[1]

	Sadoré						Bengou			Tara		
	1988			1989			1988			1989		
Treat-ment[2]	Haulm/ straw	Pods/ grain	Total	Haulm/ straw	Pods/ grain	Total	Haulm/ straw	Pods/ grain	Total	Haulm/ straw	Pods/ grain	Total
1.	0.602	1.500	0.819	0.368	0.650	0.442	5.538	0.588	1.594	1.707	7.889	2.369
2.	1.471	2.690	1.913	1.692	3.000	2.081	-3	0.732	2.808	3.169	4.039	3.435
3.	5.950	6.588	6.243	10.00	11.00	10.40	23.58	1.317	4.160	6.237	13.80	7.813
4.	0.768	3.500	1.167	0.643	1.214	0.786	5.792	0.575	1.444	2.215	2.640	2.333
5.	3.406	3.680	3.526	2.882	3.000	2.923	11.10	1.243	2.846	6.282	3.679	5.194
6.	5.222	7.800	6.143	5.375	8.167	6.136	18.87	2.200	5.141	6.744	8.909	7.220
7.	0.434	3.312	0.723	0.517	1.053	0.646	-	0.867	2.029	3.211	-	5.361
8.	2.214	3.720	2.776	2.737	5.833	3.480	11.40	1.150	2.692	2.205	4.625	2.775
9.	5.941	6.714	6.290	4.714	5.873	5.136	22.00	2.049	4.496	5.811	9.000	6.686

1. Kg of millet gained per kg of groundnut sacrificed.
2. Treatment: 1 = Millet at 1 m × 1 m and groundnut cv 55-437 (or 28-206); 2 = Millet at 1 m × 2 m and 55-437 (or 28-206); 3 = Millet at 1 m × 3 m and 55-437 (or 28-206); 4 = Millet at 1 m × 1 m and TS 32-1 (or 47-16); 5 = Millet at 1 m × 2 m and TS 32-I (or 47-16); 6 = Millet at 1 m × 3 m and TS 32-1 (or 47-16); 7 = Millet at 1 m × 1 m and ICGS(E) 11; 8 = Millet at 1 m × 2 m and ICGS(E) 11; 9 = Millet at 1 m × 3 m and ICGS(E) 11.
3. Introducing millet into groundnut did not decrease groundnut yield.

Maradi, however, this variety gave the lowest yield (0.31 t ha^{-1}). Pod yields were in general higher at Sadoré than at Tara and Maradi (Table 5). Interactions between cropping system and groundnut cultivars for pod yield at Sadoré, Maradi, and Ina were not significant. As in the previous year, a significant ($P \leq 0.05$) interaction between groundnut cultivar and cropping system was observed at Tara but was small compared with the main effect. These results further confirm that it may be possible to select in a groundnut sole crop groundnut lines that will perform well in an intercrop situation. Millet grain yields were in general higher at Tara (1.15-1.65 t ha^{-1}) than at Sadoré (0.63-0.99 t ha^{-1}).

We designed a trial aimed at improving the productivity of a millet/groundnut intercrop by modifying the relative sowing dates of the component species. We grew millet, groundnut, and millet/groundnut intercrops sown on three dates (at Sadoré 29 May, 8 Jun, and 18 Jun 1990; at Tara, 14 Jun, 3 Jul, and 16 Jul) at four nutrient levels (0, 15, 30, and 45 kg ha^{-1} of NPK) at Sadoré and Tara. Cropping system had a significant effect on yield of both millet and groundnut (Table 6): sole crops of each gave the highest yield; intercropping reduced groundnut pod and haulm yields, millet grain, and millet straw yields. Delayed sowing significantly reduced groundnut pod yield (from 0.66 to 0.14 t ha^{-1}) and

Table 5. Yield (t ha^{-1}) performance of 12 groundnut cultivars under intercropping at four locations, rainy season 1990.[1]

	Bénin		Niger							
	Ina		Maradi		Sadoré			Tara		
	Groundnut		Groundnut		Groundnut		Millet	Groundnut		Millet
Cultivar	Haulms	Pods	Haulms	Pods	Haulms	Pods	grain	Haulms	Pods	grain
TS 32-1	1.25	1.55	1.08	0.73	2.59	1.77	0.76	1.71	0.97	1.26
JL 24	1.06	1.55	1.19	0.80	2.68	1.59	0.77	1.56	0.83	1.45
47-16	1.84	1.21	1.50	0.98	1.70	1.85	0.70	1.26	0.49	1.15
ICGS(E)56	0.94	1.43	0.92	0.62	1.85	2.13	0.85	1.06	0.74	1.32
28-206	2.01	1.88	1.37	0.84	2.73	2.17	0.73	1.35	0.39	1.33
55-437	1.02	0.91	1.05	0.80	2.42	1.92	0.63	1.70	0.83	1.65
ICGMS 68	1.11	1.40	0.95	0.61	1.91	2.03	0.99	1.10	0.65	1.42
ICGMS 42	1.52	1.70	1.46	0.91	2.08	1.96	0.80	1.23	0.35	1.35
ICGS(E)13	1.01	0.93	1.17	0.89	2.47	1.85	0.64	1.27	0.70	1.45
796	0.94	0.93	0.80	0.83	1.78	1.73	0.73	0.93	0.74	1.19
ICGS(E)30	1.25	1.03	0.97	0.67	2.39	1.75	0.82	1.38	0.83	1.16
ICGS 11	0.85	1.29	0.98	0.63	1.82	1.96	0.75	1.07	0.67	1.52
SE	±0.09	±0.09	±0.09	±0.07	±0.11	±0.11	±0.13	±0.07	±0.06	±0.21
CV (%)	21	20	23	24	15	17	33	17	25	31

1. Randomized complete block design, 2-factor factorial with 4 replications; plot size 18m^2.

Table 6. Performance of millet/groundnut intercrops in relation to millet sowing dates, ISC, rainy season 1990.

	Yield (t ha^{-1})			
	Groundnut		Millet	
Treatment	Haulms	Pods	Straw	Grain
Intercrop				
1. Millet sown before groundnut	0.47	0.40	1.71	0.51
2. Millet and groundnut sown simultaneously	0.56	0.51	1.67	0.49
3. Millet sown after groundnut	0.56	0.66	1.41	0.40
Sole crop (sown on the same date as treatment 2)				
4. Groundnut	1.16	1.08		
5. Millet			2.55	0.84
SE	±0.14	±0.13	±0.22	±0.08
CV (%)	41	42	25	31

millet grain yield (from 1.76 to 0.41 t ha^{-1}) at Tara, as the crops matured well after the rains had stopped. At Sadoré, the response was rather erratic because of the poor distribution of rainfall during the 1990 cropping season. Millet grain yield was somewhat higher with fertilizer than without.

We conducted another field trial at Sadoré with millet (1 × 1 m spacing) and groundnut (50 × 10 cm spacing) in five treatments). Delayed sowing of millet in the intercrop had no significant effect on the haulm and pod yields of groundnut. The highest millet and groundnut yields were obtained with sole crops (Table 6).

Crop Rotation

Katombora rhodes grass (*Chloris gayana*) has been used successfully in some parts in eastern Africa as a rotation crop in tobacco fields, which tend to be infested with nematodes under continuous tobacco cultivation. We initiated a long-term trial in 1989 at Sadoré and Tara using Katombora rhodes grass in the rotation. The performance of millet, groundnut, or millet/groundnut intercrop after Katombora rhodes grass was inconsistent (Table 7). However, the nematode population at Sadoré was markedly reduced in the plots that had rhodes grass in the previous year.

Table 7. Effect of Katombora rhodes grass on the performance of millet and groundnut and nematode population in the subsequent year at Tara and Sadoré, Niger, rainy season 1990.[1]

		Tara				Sadoré				Total[3] nematode count (in 100 cm^3 soil)
		Yield (t ha^{-1})				Yield (t ha^{-1})				
Treat-ment[2]	Cropping system	Groundnut		Millet		Groundnut		Millet		
1989	1990	Haulms	Pods	Straw	Seed	Haulms	Pods	Straw	Seed	
R	G	1.30	1.68	-	-	1.95	1.30	-	-	0.68
R	M	-	-	3.03	1.61	-	-	2.17	0.61	1.24
R	G/M	0.31	0.63	-	-	1.47	0.89	1.47	0.42	1.70
R	G	1.01	1.40	3.30	1.46	1.83	1.18	-	-	0.77
R	M	-	-	3.35	1.67	-	-	2.83	0.85	1.19
R	G/M	0.64	1.00	-	-	1.74	1.09	0.63	0.24	1.14
G	G	0.69	2.24	1.28	0.68	2.23	1.48	-	-	3.30
M	M	-	-	3.21	1.54	-	-	2.98	0.97	3.03
G/M	G/M	0.21	0.88	-	-	1.30	0.74	2.02	0.68	2.92
G/M	G	0.82	1.95	3.09	1.51	1.65	1.24	-	-	2.35
G	M	-	-	3.98	1.78	-	-	3.47	0.96	2.69
M	G/M	0.65	1.03	1.31	0.61	1.80	1.14	1.14	0.37	2.02
	SE	±0.07	±0.22	±0.28	±0.15	±0.17	±0.08	±0.39	±0.13	±0.15
	CV (%)	19	13	19	22	19	13	36	39	15

1. Randomized complete block design with 4 replications; plot size 6 m^2.
2. R = Rhodes grass; G = groundnut ; M= millet (sown at 1 × 1m in 1989; sown at 1 × 2m in treatments 6 and 12); G/M = Groundnut intercropped with millet.
3. Nematode count data has been transformed using the equation x = Log(x+1) where x is the nematode no. obtained in the count.

Biotic Stresses

Yield Losses from Foliar Diseases in West Africa

During the 1990 rainy season we conducted a foliar diseases trial at nine locations in West Africa: Bengou, Maradi, and Sadoré in Niger; Ina and Niaouli in Bénin; Bobo-Dioulasso in Burkina Faso; and one location each in Cameroon, the Gambia, and Guinea. Disease pressure was quite variable during the season because of rainfall variability across locations.

Diseases were not severe at Maradi and Sadoré. Early leaf spot (*Cercospora arachidicola)* was the most serious disease at Bengou, appearing 50 days after sowing (DAS) and progressing rapidly; however, this progress was slowed by drought from mid-August to the end of the rainy season. Average pod yield with application of Corvet CM® fungicide was 3.11 t ha^{-1} compared with 2.57 t ha^{-1} without; line ICGS 11 yielded the highest–4.38 t ha^{-1} with and 2.97 t ha^{-1} without fungicide. This represented a 33% yield loss. Yield losses were significantly lower in foliar-disease resistant lines such as ICG(FDRS)4 and ICG(FDRS)10 (Table 8).

At Ina, Bénin, late leaf spot (*Phaeoisariopsis personata)* was the most important disease during the season. Rust (*Puccinia arachidis)* occurred late in the season and damage was most severe on long-duration lines. Average yield with fungicide application was 2.94 t ha^{-1} compared with the control, which gave 2.06 t ha^{-1}. ICG(FDRS)10, 55-437, and ICGS 11 showed yield losses of 24, 41, and 21%, respectively, when grown without fungicide treatment (Table 8).

Table 8. Performance of six groundnut genotypes with and without fungicide treatment to control foliar diseases in Niger and Bénin, rainy season 1990.[1]

	Bengou (Niger)		Ina (Bénin)	
Genotype	Pod yield (t ha^{-1})	% Leaf area damage	Pod yield (t ha^{-1})	% Leaf area damage
Treated with Corvet CM®				
28-206	2.51	0.65	2.86	9.0
55-437	3.07	7.16	3.17	22.5
47-16	3.03	0.89	2.23	4.6
ICGS 11	4.38	1.63	3.05	26.8
ICG(FDRS) 4	2.34	0.28	2.99	6.7
ICG(FDRS) 10	3.31	3.76	3.33	16.5
Nontreated				
28-206	2.38	42.75	1.95	73.9
55-437	2.34	73.50	1.27	78.5
47-16	2.73	46.25	1.81	66.7
ICGS 11	2.97	72.00	2.40	67.8
ICG(FDRS) 4	2.10	33.75	2.42	50.3
ICG(FDRS) 10	2.88	57.25	2.53	58.5
SE	±0.05	±2.09	±0.13	±2.6
Mean (treated)	3.11	2.40	2.94	14.4
Mean (nontreated)	2.57	54.25	2.06	66.0
SEm	±0.05	±2.09	±0.10	±3.41
Trial mean	2.84	28.32	2.50	40.1
CV (%)	13	27	10	13

1. Split-plot design with 4 replications; plot size 8m^2.

In Burkina Faso, rust, early leaf spot, and late leaf spot were present, but early leaf spot did not damage the crop. We used a selective fungicide to measure losses from either rust or late leaf spot. The average pod yield with Bavistin® (which controls leaf spots) was 1.90 t ha^{-1}, whereas with Corvet CM® (which controls rust and leaf spots) it was 2.46 t ha^{-1}. The control treatment yielded 1.57 t ha^{-1}. The interaction between genotypes and fungicide application was significant (Table 9), mainly due to ICG (FDRS)2 and ICG (FDRS)70, which are resistant to rust. These genotypes yielded almost the same when treated with either Corvet CM® or Bavistin®. In the control treatment with no fungicide, these lines produced nearly 50% fewer pods because of their susceptibility to late leaf spot.

Table 9. Performance (pod yield t ha^{-1}) of six groundnut genotypes under fungicide treatments to control foliar diseases in Burkina Faso; rainy season 1990.[1]

Genotype	Fungicide		Control (No fungicide)
	Covert CM®	Bavistin®	
28-206	2.99	1.92	1.64
ICG(FDRS) 70	2.79	2.53	1.57
ICGS11	2.73	2.22	1.14
55-437	2.51	1.84	1.08
ICG(FDRS) 2	2.30	2.21	1.03
47-16	1.43	0.70	0.52
Trial mean (6 entries)	2.46	1.90	1.57
SE of genotype mean	±0.15		
CV (%)	17		

1. Split-plot design with 4 replications; plot size = 10.8 m^2

Screening for Resistance to Foliar Diseases

Early leaf spot, late leaf spot, and rust were present in the region during the 1990 rainy season. Their severity varying from one location to another.

We sowed our screening trials in different "hot spots" during the season. Screening for rust was conducted at Niangoloko, near Bobo-Dioulasso (Burkina Faso); for early leaf spot, at Bengou (Niger), and Foullayah (Guinea); and for late leaf spot, in Niger, Burkina Faso, and Guinea.

Early Leaf Spot

Sixty-four germplasm lines were screened for resistance to early leaf spot at Bengou in Niger; they included lines that we reported resistant in 1989 and some new germplasm lines with resistance to late leaf spot. Out of 64 lines tested, 20 were scored less than 4 (on a 1-9 scale where 1 = no disease and 9 = 50-100% foliage damage). ICG 7892, ICG 7878, and ICG 1703 were the most resistant. As in 1989 (ICRISAT West African Programs Annual Report 1989, p. 35), ICG lines 7878, 6284, 7756, and 1707 showed stable resistance in 1990 (Table 10). In addition, they also showed resistance to late leaf spot.

Table 10. Reaction of selected groundnut genotypes to early (ELS) and late (LLS) leaf spots, Bengou, Niger, rainy season 1990.[1]

Genotype	Disease rating[2]		Yield (t ha^{-1})	
	ELS	LLS	Haulms	Pods
ICG 7892	2.3	3.3	1.00	0.73
ICG 7878	2.4	2.3	4.17	0.99
ICG 1703	2.4	3.3	2.89	0.95
ICG 10923	2.5	3.7	3.72	0.92
ICG 10883	2.6	2.7	4.61	0.87
ICGMS 55	2.6	3.7	7.00	1.48
ICG 10917	2.7	3.7	3.28	0.94
ICG 11072	2.7	4.3	3.44	0.78
ICG 11185	2.9	3.0	1.56	0.34
ICG 7630	3.1	5.3	3.06	1.37
ICG 10954	3.2	5.0	3.33	1.71
ICG 7893	3.2	5.3	3.11	0.72
NC Ac 15993	3.3	4.3	2.39	0.71
ICG 10900	3.4	5.7	5.67	1.73
ICG 10022 (A)	3.4	5.0	1.61	0.40
ICG 6284	3.6	4.3	3.06	0.87
ICG 1007	3.6	1.0	2.83	0.84
ICG 7756	3.8	1.3	4.94	1.57
ICG 6280	3.9	4.3	3.78	1.07
ICG 8298	3.9	3.3	5.06	2.05
ICG 7226	4.0	4.0	4.39	1.00
ICG 10948	4.0	5.7	2.89	1.29
ICGV 86690	4.2	2.3	2.50	0.27
USA 63	4.3	2.7	2.11	0.89
ICG 7888	4.3	2.3	2.94	0.32
ICG 8339	4.3	4.3	3.94	1.35
ICG 10 000	4.3	5.0	3.83	0.78
ICG 2711	4.4	4.3	4.39	1.69
ICGMS 42	5.3	3.0	4.78	1.83
47-16	7.7	4.3	3.89	1.58
ICG 7789	8.0	5.7	4.89	1.79
ICGS 11	8.2	4.7	3.11	1.30
ICG 11179	8.3	4.0	4.11	1.01
55-437	8.8	7.0	5.50	1.66
SE	±0.66	±0.70	±0.62	±0.20
CV (%)	22	32	27	28

1. In 8 × 8 lattice with 3 replications; plot size 6m^2.
2. Scored on a 1-9 scale where 1 = no disease and 9 = 50 to 100% foliage damage.

Late Leaf Spot

Ninety-eight germplasm and breeding lines were tested in two separate trials at Bengou and at Bobo-Dioulasso. At Bengou, 42 lines scored less than 4 (on 1-9 scale). Of those reported resistant to late leaf spot at ICRISAT Center, ICG

2716, 6340, 7013, and 7741; NC Ac 17132, and NC Ac 17133(RF) showed very high levels of resistance, with scores of less than 2. Lines such as ICGs 6284, 1707, 10028, 4747, reported resistant at Bengou (ICRISAT West African Programs Annual Report 1989 p.39), showed a stable resistant reaction to late leaf spot (Table 11). Only ICGs 1707, 7888, and USA 63, with resistance to late leaf spot, showed some resistance to early leaf spot as well.

Disease pressure was lower at Bobo-Dioulasso than Bengou. Only highly susceptible lines such as 55-437 had a score of 8.3 (on a 1-9 scale). Lines such as ICGs 1707, 2716, 4747, and 6340 showed resistance to leaf spot in both Niger and Burkina Faso (Table 11).

Table 11. Reaction of selected groundnut germplasm and breeding lines to late leaf spot (LLS) in West Africa, rainy season 1990.[1]

Bengou, Niger				Bobo-Dioulasso, Burkino Faso	
Trial 1		Trial 2			
Genotype	LLS[2]	Genotype	LLS	Genotype	LLS
ICG 10756	1.8	ICG 2716	1.3	ICG 1707	1.0
ICG 6340	1.8	NC Ac 17132	1.4	ICG 1710	1.0
ICGV 87779	2.2	ICG 7013	1.6	ICG 2716	1.0
ICG 7741	2.3	NC Ac 17133 NC	1.6	ICG 4747	1.0
ICG 4747	2.3	Ac 17506	1.6	ICG 4790	1.0
ICGV 87219	2.3	USA 63	1.7	ICG 4995	1.0
ICG 6434	2.5	PI 215 696	1.7	ICG 6330	1.0
ICG 10920	2.6	NC Ac 927	1.8	ICG 6340	1.0
ICG 5270	2.7	ICG 10941	1.9	ICG 7881	1.0
ICG 10028	2.7	ICG 10936	1.9	ICG 7884	1.0
ICG 7756	2.8	ICG 6330	1.9	ICG 7885	1.0
ICG 9989	2.8	ICG 10039	1.9	ICG 7897	1.0
ICGMS 42	2.9	ICG 1707	2.0	ICG 86699	1.0
2169-1-1	3.0	PI 381 622	2.1	ICG 7630	1.3
ICG 10075	3.0	PI 350 680	2.1	ICG 7888	1.3
21-92-4	3.4	ICG 4790	2.4	ICG 10889	1.3
ICGMS55	3.6	ICG 10949	2.8	ICG 10936	1.3
ICG 7671	3.8	PI 259 747	3.3	ICGV 86687	1.7
ICG (FDRS)37	3.8	NC Ac 17135	3.5	ICG 10028	2.7
ICG 10030 A	7.7	796	7.1	USA 63	3.3
55-437	7.9	55-437	8.2	55-437	8.3
SE	±0.77		±1.22		±0.3
CV (%)	31		51		16
Lattice efficiency (%)	103		104		< 100

1. A 7 × 7 lattice in Niger (6 × 6 in Burkina Faso) with 3 replications; plot size 8 m² for trial 1 and 1.6 m² for trial 2.
2. Late leaf spot reaction scored on a 1-9 scale where 1=no disease and 9=50-100% foliage damage.

Rust

To check the stability of rust resistance in lines reported resistant at ICRISAT Center, we conducted a trial at Bobo-Dioulasso. One hundred germplasm and breeding lines and interspecific derivatives were tested; 69 had scores of less than 4 (on a 1-9 scale). Almost all resistant lines selected at ICRISAT Center showed resistance to rust in Burkina Faso. Some of the ICRISAT foliar disease resistant breeding lines such as ICG(FDRS)37, ICG(FDRS)12, ICG(FDRS)50, ICG(FDRS)4, and ICG(FDRS)20 showed good levels of resistance to rust. Among the cytogenetic material, 799, 420, CS 52, and 330 were found to be resistant to rust. Lines with multiple disease resistance have been identified from these trials (Tables 10, 11, 12).

Table 12. Stability of rust resistance in groundnut germplasm and breeding lines in West Africa; Bobo-Dioulasso, Burkina Faso, rainy season 1990.[1]

Genotype	Disease reaction[2]	Genotype	Disease reaction	Genotype	Disease reaction
ICG 10030 A	1.9	ICG 10032	2.1	NC Ac 17506	3.6
PI 270 806	1.9	ICG 10933	2.1	PI 393 527B	3.7
ICG 10022 B	1.9	ICG (FDRS)12	2.1	NC Ac 17133	3.8
ICG 10014	2.0	ICG 10974	2.1	330	4.0
ICG 10022 A	2.0	799	2.2	NC Ac 17135	4.0
ICG 10918	2.0	ICG 10074	2.2	NC Ac 927	4.1
ICG 10048	2.0	ICG 10064 A	2.2	ICG 10035	4.2
ICG 10963	2.0	ICG 10068	2.2	ICG 7888	4.3
ICG (FDRS)37	2.0	ICG 6930	2.3	ICG 10936	4.5
NC Ac 17090	2.0	ICG (FDRS)50	2.3	ICG 7630	4.7
ICG 10928	2.0	ICG 10945	2.3	PI 215 696	4.7
ICG 10031	2.0	PI 381 622	2.3	NC Ac 17132	4.7
ICG 10053	2.0	420	2.3	ICG 10010	4.9
ICG (FDRS)6	2.0	ICG 10978	2.3	1108	5.0
ICG 10042	2.0	ICG 11080	2.3	ICG 6284	5.0
EC 76446(292)	2.0	ICG 11108	2.3	ICG 10941	5.1
ICG 10966	2.1	CS 52	2.3	USA 63	5.3
ICG 10020	2.1	ICG 11183	2.4	PI 390 595	5.4
PI 393 526	2.1	ICG 10054	2.4	ICG 10975	5.8
ICG 10039	2.1	PI 393 643	2.4	RMP 12	5.9
ICG 10935	2.1	ICG 10061	2.4	ICG 10016	6.0
ICG 10969	2.1	ICG 9185 A	2.4	ICG 7433	6.1
PI 414 331	2.1	ICG 11182	2.4	ICG 10028	6.1
ICG 10021	2.1	ICG 10889	2.4	ICG (FDRS)27	6.3
PI 393 531	2.1	ICG 10939	2.4	69-101	6.3
ICG 10964	2.1	ICG 10034	2.5	ICG (FDRS)15	6.3
ICG 10051	2.1	PI 350 680	2.6	28-208	6.7
ICG 10884	2.1	ICG 7296	2.7	ICGS 11	6.9
PI 390 593	2.1	PI 393 646	2.8	47-16	7.1
ICG 10940	2.1	PI 315 608	2.8	EC 76446(SP)	7.2
ICG 10047	2.1	ICG (FDRS)4	3.3	55-437	7.4
PI 259 747	2.1	ICG (FDRS)20	3.3	796	7.4
PI 405 132	2.1	ICG 5043	3.4	TS 32-1	7.7
SE	± 0.27		± 0.27		± 0.27
CV (%)	14		14		14
Lattice efficiency (%)	125		125		125

1. A 10 × 10 lattice with 3 replications; plot size 2.25 m².
2. Scored on a 1-9 scale, where 1 = no disease and 9 = 50-100% foliage damage.

Table 13. Performance of selected groundnut genotypes in groundnut foliar disease resistance screening trial, Bengou, Niger, rainy season 1990.[1]

Genotype	Disease rating[2]		Yield (t ha^{-1})		Def (%)[3]
	ELS	LLS	Haulms	Pods	
ICGV 87281	8.00	6.67	4.30	2.32	60.67
ICGM 197	4.33	8.67	3.50	2.21	60.67
ICGV 86594	8.67	8.00	3.87	2.19	55.00
ICG(FDRS) 272	8.33	7.33	3.60	2.18	60.00
ICGV 86680	6.00	8.00	3.93	2.12	35.00
ICGM 614	7.67	7.00	3.90	2.12	44.33
28-206	9.00	7.67	3.70	2.05	63.33
ICGV 86600	8.33	9.00	2.97	2.03	86.67
ICGV 86675	8.33	7.00	4.97	2.03	55.00
ICGV 87160	7.33	5.33	4.90	2.01	53.33
ICGV 87306	8.67	6.67	3.60	1.91	58.33
ICGV 87171	7.00	8.67	3.63	1.89	76.67
ICGV-SM 85053	8.33	8.00	3.40	1.88	78.33
ICGV 87185	6.67	7.33	4.07	1.81	46.67
ICGV 87290	9.00	7.67	3.87	1.80	70.00
ICGV 86659	8.67	7.33	3.33	1.79	65.00
ICGV 86699	8.33	6.67	4.33	1.78	56.67
ICGV 87356	8.00	5.00	4.73	1.78	36.67
ICGV 87771	6.67	8.00	3.67	1.73	85.00
ICGV-SM 85043	7.00	4.33	4.93	1.73	46.67
ICGV 87167	9.00	7.33	3.37	1.73	73.33
ICGV 86591	4.33	6.33	5.13	1.71	40.00
ICGV 87773	9.00	7.67	3.03	1.69	63.33
ICGV 87157	7.67	6.67	4.80	1.68	54.33
ICG(FDRS) 12	8.33	7.33	4.27	1.68	46.67
ICGV 87169	8.33	8.33	4.30	1.63	60.00
ICGV 87240	8.33	6.67	4.30	1.60	56.67
ICGV 87163	6.67	6.00	3.80	1.57	70.00
ICGV 87159	7.33	4.67	4.67	1.51	41.67
ICGV 87164	6.67	4.00	3.70	1.50	26.67
ICGV 86687	5.67	4.00	6.20	1.48	15.83
ICGV 87183	6.33	6.67	4.27	1.41	36.67
ICGV 87174	8.33	4.33	4.90	1.39	48.33
ICGV 87262	8.33	6.00	3.67	1.34	36.67
ICGV 87166	7.33	6.67	4.60	1.28	51.67
ICGV 87123	5.33	5.00	4.53	1.27	18.33
SE	±1.07	±1.51	±0.40	±0.5	±15.81
CV (%)	25	39	17	15	51
Lattice efficiency (%)	<100	<100	<100	116	<100

1. A 6 × 6 lattice with 3 replications, plot size 8 m^2.
2. ELS = early leaf spot; LLS = late leaf spot; disease reaction scored on a 1-9 scale where 1 = no disease and 9 = 50-100% foliage damage.
3. Def = Defoliation.

Evaluating Yield and Resistance to Foliar Diseases

Sixty-six foliar-disease resistant breeding lines from ICRISAT Center were assessed for yield and disease reaction; 10 gave pod yields as good as the local cultivar 28-206. Two lines, ICGM 197 and ICGV 86591, had a score of 4.3 (on a 1-9 scale) for early leaf spot; only ICGM 197 is among the high-yielding lines. Eight other lines showed tolerance to late leaf spot, with scores of 5 or less. But none of these were among the top 10 (Table 13). There was no correlation between pod yield and disease score. ICGV 86680, 86687, and 87164 showed good leaf retention.

Seedling Diseases

During the 1990 rainy season a trial was sown at three locations in Niger (Bengou, Maradi, and Sadoré). Half the seeds were treated with fungicide (thiram) at the rate of 3 g kg^{-1} of seed. The results were similar to those obtained in the 1989 rainy season: seedling mortality was much less when seed protectant was used. Seedling losses varied from 4 to 15% with fungicide and 7 to 39% without fungicide, depending on the location and genotype (Table 14).

Table 14. Assessment of yield losses from seedling diseases of groundnut at three locations in Niger, 1990.[1]

	Bengou		Maradi		Sadoré	
Genotype	Pod yield (t ha^{-1})	Plant losses (%)	Pod yield (t ha^{-1})	Plant losses (%)	Pod yield (t ha^{-1})	Plant losses (%)
Treated 1						
1	1.69	4.81	1.53	8.00	1.16	6.07
2	2.08	9.56	0.99	15.62	0.86	7.40
3	1.47	10.72	0.75	7.35	0.81	7.52
4	1.31	6.09	1.32	12.40	0.91	3.96
Nontreated						
1	1.59	13.46	1.38	16.32	1.19	7.00
2	1.68	19.72	0.46	38.98	0.73	28.44
3	1.12	15.63	0.50	10.97	0.54	18.39
4	1.11	16.46	1.31	18.24	0.96	12.58
SE	±0.14	±3.23	±0.18	±3.37	±0.13	±2.51
CV (%)	19	54	36	42	30	44

1. Randomized block design with 4 replications; plot size 16 m^2.

Aflatoxin Contamination

Twenty-five lines were tested for aflatoxin resistance in a multilocational trial in West Africa. In Niger, the average seed contamination by *Aspergillus flavus* was variable, being highest at Sadoré (24.9%), but much lower at Maradi (5.2%) and Bengou (5.6%). We found significant differences among genotypes. All known resistant lines (such as PI 337394F, J 11, 55-437, U4-47-7, and AH 7223) were among the less-contaminated ones at all three locations in Niger. Among the ICRISAT advanced breeding lines considered resistant to *A. flavus*, ICGV 87094, 87110, and 87107 maintained their resistance. At Sadoré, several genotypes showed very high seed contamination, 44-66% (Table 15).

Table 15. Seed contamination by *Aspergillus flavus* in some groundnut genotypes in Niger, rainy season 1990.[1]

Genotype	Sadoré		Bengou		Maradi	
	Infected seed (%)		Infected seed (%)		Infected seed (%)	
55-437	3	(9.40)[2]	2	(7.96)	2	(5.21)
PI 337394 F	4	(7.96)	1	(3.84)	1	(8.77)
J 11	4	(12.61)	1	(3.84)	2	(8.14)
ICGV 87110	6	(13.29)	2	(8.14)	3	(9.85)
U4-47-7	7	(14.27)	0	(0.00)	2	(7.96)
Ah 7223	8	(15.81)	3	(9.34)	4	(11.00)
UF 71513-1	10	(16.79)	2	(7.96)	3	(9.34)
ICGV 87106	12	(20.23)	2	(7.33)	4	(10.77)
U1-2-1	13	(20.51)	1	(6.53)	3	(9.85)
ICGV 87101	14	(21.60)	5	(12.38)	8	(16.79)
T2 32-1	15	(22.46)	4	(11.46)	8	(15.47)
ICGV 87084	16	(23.49)	4	(11.34)	9	(17.25)
ICGV 87107	17	(24.47)	2	(6.65)	8	(11.34)
ICGV 87094	17	(23.95)	3	(9.34)	2	(7.96)
ICGV 87109	20	(25.38)	2	(8.54)	8	(15.64)
ICGV 87089	28	(30.71)	3	(7.05)	2	(7.96)
28-206[3]	31	(33.23)	3	(9.11)	6	(14.04)
ICGV 87095	37	(36.44)	3	(7.85)	2	(7.68)
ICGV 87112	38	(37.30)	7	(15.18)	2	(6.99)
69-101	41	(40.11)	19	(25.78)	3	(9.97)
JL 24	44	(41.99)	2	(5.79)[4]	12	(20.51)
VAR 27	54	(47.38)	6	(13.64)	8	(16.79)
756 A[3]	56	(48.93)	4	(11.92)	7	(14.84)
ICGV 87108	62	(52.83)	5	(13.29)	16	(23.55)
CS 52[3]	66	(54.37)	54	(47.33)	10	(18.05)
SE	±1.3	(±5.61)	±8.96	(±4.01)	±1.78	(±1.66)
Trial mean (25 entries)	5.2	(27.85)	24.9	(10.86)	5.6	(12.23)
CV (%)	43	(35)	62	(35)	55	(24)
Lattice efficiency (%)	<100	(107)	104	(101)	<100	(<100)

1. A 5 × 5 lattice with 3 replications; plot size 8 m².
2. Figures in parentheses are arc sine transformed values.
3. At Bengou genotypes 28-206, 765 A, and CS 52 were replaced by 73-30, 73-33, and 73-27 respectively.
4. Insufficient seeds were available for a reliable test.

Crop Growth Variability

Nematodes, peanut clump virus (PCV), and nutrient imbalances have been found to play an important role in crop growth variability at Sadoré. In early 1989, we began a long-term trial on the effect of lime and carbofuran on soil pH, Al toxicity, nematode population, and groundnut yield: groundnut was sown during the rainy season 1989, followed by pearl millet in the dry season 1989/90, and groundnut again in the 1990 rainy season.

Effect of Lime and Carbofuran on Crop Growth Variability

In 1989, carbofuran increased groundnut pod yield, but lime application did not affect soil pH or Al^{+++} content and did not increase groundnut yield. In the 1990 rainy season, however, lime applied at 10 t ha^{-1} increased pH, decreased

Al^{+++}, improved crop growth, and increased groundnut pod yield to the same level as that obtained with the carbofuran treatment. Lime had no effect on the nematode population, which was reduced by the carbofuran (Table 16). This finding shows the important role of Al toxicity in groundnut cropping and will be exploited to develop a practical management system for the control of crop growth variability.

Table 16. Effect of lime and carbofuran on groundnut yield, soil pH, soil Al content, and nematode populations at ISC, rainy season 1990.[1]

Lime (t ha^{-1})	1989 Pod yield (t ha^{-1})	1990 Pod yield (t ha^{-1})	1990 pH Sowing	1990 pH Harvest	1990 Al^{+++} Sowing	1990 Al^{+++} Harvest	Nematode population (in 100 cm^3 soil)
With carbofuran							
0	2.12	1.82	4.11	4.00	0.31	0.26	21
5	2.03	1.77	4.23	4.25	0.24	0.14	55
10	2.23	1.75	4.32	4.67	0.19	0.08	71
20	2.35	1.82	4.74	5.16	0.08	0.02[2]	74
Without carbofuran							
0	1.02	0.88	4.11	3.99	0.29	0.25	172
5	0.95	1.34	4.22	4.38	0.26	0.11	139
10	1.01	1.79	4.40	4.82	0.14	0.02	154
20	1.13	1.88	4.82	5.22	0.06	0.01[2]	139
SE	±0.17	±0.16	±0.10	±0.12	±0.034	±0.025	±20
CV (%)	25	23	5	6	41	48	47

1. Split-plot design with 6 replications; plot size 16m^2.
2. The fourth level of lime was not included in the calculation of the SE because 9 of the 12 values were less than 0.005.

Host Range Studies

Host range of nematodes. In collaboration with ICRISAT Center, we studied the host range of *Scutellonema clathricaudatum*, *Xiphinema parasetariae*, and *Tylenchorhynchus* spp. in an infested field at Sadoré. The nematode population was determined in the root and rhizosphere of 13 crops. Variation in nematode population density between crops was highly significant ($P<0.001$). The highest levels of nematodes were found in the rhizosphere of millet (2625), groundnut (1982), sorghum (14215), cowpea (1232), sunflower (1152), and bambara groundnut (1047)±345 per 100 cm^3 of soil. Other crops showed lower population densities.

The most prevalent was the endoparasitic nematode, *S. clathricaudatum*, which was found in the roots of all 13 crops we tested; the mean population was highest in millet. Sorghum, maize, and millet showed the highest number of *Tylenchorhynchus* spp.; *X. parasetariae* population was high only in the rhizosphere of sesamum.

Host Range of PCV. In collaboration with ORSTOM, IRHO, and ICRISAT Center, we studied the host range of PCV, using the same 13 crops used in the nematode study. ELISA test showed that PCV has a wide host range that includes not only groundnut but also cereals such as millet and maize. The highest concentrations of PCV antigen were found in groundnut, pigeonpea, millet, bambara groundnut, and maize. Sunflower was the only crop that did not contain PCV antigen.

Plant Improvement

Yield Trials

Medium- and Late-Maturing Lines

This trial consisted of 14 lines obtained from the SADCC/ICRISAT Malawi and ICRISAT Center (IC) programs. These, along with two widely adapted controls, were tested at five locations in West Africa. ICGV 86528 ranked highest when averaged over locations, but ICGV 86529 was most consistent in performance at all sites in Niger (Table 17). Overall, these two lines yielded higher than the local controls.

Table 17. Yield performance of selected medium- and late-maturing lines in the Advanced Groundnut Varietal Trial (AGVT) at five locations in West Africa, rainy season 1990.[1]

	Pod yield (t ha^{-1})					
Genotype	Mean of 5 sites	INRAN, Bengou	INRAN, Maradi	ISC, Sadoré	DRA, Ina, (Bénin)	Sierra Leone
ICGV SM 83708	2.14 (13)[2]	2.38 (14)	1.57 (15)	2.36 (6)	2.38 (4)	2.00 (3)
ICGV SM 83709	2.36 (6)	2.47 (12)	2.33 (10)	2.68 (2)	2.62 (2)	1.67 (10)
ICGV SM 85005	2.24 (10)	3.20 (4)	2.43 (9)	2.41 (5)	1.81 (15)	1.33 (15)
ICGV SM 85038	2.41 (5)	2.44 (13)	2.65 (7)	2.98 (1)	2.31 (7)	1.67 (8)
ICGV SM 85764	2.35 (8)	3.22 (3)	2.18 (12)	2.35 (7)	2.65 (1)	1.33 (12)
ICGV SM 86725	2.42 (4)	2.83 (8)	2.76 (5)	2.34 (8)	2.16 (10)	2.00 (4)
ICGV SM 87707	2.08 (15)	2.57 (10)	2.06 (13)	1.56 (16)	2.20 (9)	2.00 (2)
ICGV 86024	2.30 (9)	2.58 (9)	2.65 (6)	2.26 (10)	2.31 (6)	1.67 (5)
ICGV 86028	2.45 (1)	3.11 (5)	3.49 (1)	2.46 (4)	1.84 (14)	1.33 (14)
ICGV 86529	2.43 (2)	3.27 (2)	3.12 (2)	2.64 (3)	1.48 (16)	1.67 (11)
ICGV 87123	2.35 (7)	2.99 (7)	2.88 (4)	2.08 (12)	2.11 (13)	1.67 (9)
ICGV 87141	2.18 (12)	3.00 (6)	2.19 (11)	2.16 (11)	2.22 (8)	1.33 (13)
ICGV 87157	2.22 (11)	2.48 (11)	2.59 (8)	1.56 (15)	2.14 (11)	2.33 (1)
ICGV 87281	2.43 (3)	3.34 (1)	2.99 (3)	2.01 (13)	2.13 (12)	1.67 (6)
Controls						
28-206	2.11 (14)	2.22 (15)	1.97 (14)	2.26 (9)	2.44 (3)	1.67 (7)
47-16	1.60 (16)	1.71 (16)	1.04 (16)	1.86 (14)	2.37 (5)	1.00 (16)
SE	±0.10	±0.14	±0.24	±0.24	±0.20	±0.30
Trial mean (16 entries)	2.25	2.74	2.43	2.25	2.20	1.65
CV (%)	17	9	17	19	16	34
Lattice efficiency (%)	<100	102	<100	130	107	<100

1. A 4 × 4 lattice with 3 replications; plot size 10 m^2.
2. Numbers in parentheses are rankings of entries at each location.

Early-Maturing Lines

In this trial, 12 early-maturing lines along with 4 local controls were evaluated at 3 locations in Niger, one in Bénin, and one in Sierra Leone. ICGV 86015 recorded the highest pod yields at locations in Niger but ranked fifth in Bénin and Sierra Leone (Table 18). The other lines were rather variable in their performance but were generally as good as, or better than the local controls. The average time to maturity was 97 days.

Table 18. Performance of early-maturing lines in the Advanced Groundnut Varietal Trial (AGVT) at five locations in West Africa,rainy season 1990.[1]

Genotype	Pod yield (t ha^{-1}) Mean of 5 sites	INRAN, Bengou	INRAN, Maradi	ISC, Sadoré	DRA, Ina, (Bénin)	Sierra Leone
ICGV SM 83011	2.34 (11)[2]	2.93 (2)	3.47 (6)	1.65 (14)	2.21 (2)	1.42 (16)
ICGV-SM 85043	2.39 (8)	2.65 (12)	3.52 (4)	2.03 (7)	1.70 (10)	2.03 (9)
ICGV-SM 85045	2.50 (3)	2.88 (4)	3.31 (11)	1.86 (11)	2.43 (1)	2.01 (10)
ICGV 86015	2.73 (1)	3.15 (1)	3.82 (1)	2.46 (1)	1.96 (5)	2.24 (5)
ICGV 86047	2.17 (15)	2.41 (16)	2.81 (16)	2.20 (4)	1.33 (15)	2.11 (8)
ICGV 86055	2.33 (12)	2.49 (14)	3.40 (8)	2.43 (2)	1.32 (16)	2.01 (11)
ICGV 86063	2.45 (4)	2.65 (11)	3.60 (3)	2.01 (5)	1.68 (12)	2.22 (6)
ICGV 86072	2.40 (7)	2.77 (7)	3.47 (5)	1.65 (15)	1.73 (9)	2.40 (2)
ICGV 86756	2.32 (13)	2.82 (5)	3.45 (7)	1.85 (12)	1.83 (6)	1.62 (15)
ICGV 87003	2.42 (6)	2.78 (6)	3.35 (10)	1.81 (13)	1.77 (8)	2.40 (3)
JL 24	2.60 (2)	2.72 (9)	3.28 (12)	1.92 (9)	2.21 (3)	2.88 (1)
ICG 836	2.43 (5)	2.72 (8)	3.19 (14)	1.92 (10)	2.18 (4)	2.12 (7)
Controls						
55-437	2.16 (16)	2.57 (13)	3.24 (13)	1.97 (8)	1.35 (14)	1.65 (14)
796	2.36 (9)	2.43 (15)	3.37 (9)	2.04 (6)	1.64 (13)	2.32 (4)
TS 32-1	2.36 (10)	2.91 (3)	2.84 (15)	2.37 (3)	1.83 (7)	1.86 (12)
WB-9	2.28 (14)	2.67 (10)	3.68 (2)	1.62 (16)	1.69 (11)	1.74 (13)
SE	±0.08	±0.10	±0.22	±0.22	±0.16	±0.15
Trial mean (16 entries)	2.39	2.72	3.36	1.99	1.80	2.07
CV (%)	14	6	11	19	16	13
Lattice efficiency (%)	<100	<100	<100	132	109	101

1. A 4 × 4 lattice with 3 replications; plot size 10m^2.
2. Numbers in parentheses are rankings of entries at each location.

Intermediate Groundnut Variety Trial

We evaluated 58 lines originating from Chad, SADCC/ICRISAT, Malawi, and IC along with six local controls at three locations in Niger. At Bengou, mean pod yields ranged from 1.43 t ha^{-1} to 2.6 (±0.17) t ha^{-1}. Twenty-four lines gave pod yields of over 2 t ha^{-1}, while 55-437, the best cultivar in the region, averaged 1.49 t ha^{-1}. At Maradi, pod yields were much higher than at Bengou and ranged from 1.6 t ha^{-1} to 3.50 ± 0.22 t ha^{-1}, with ICGV 86124 giving a pod yield of 3.42 t ha^{-1}. At Sadoré, pod yields were generally low, except for IBPGR 316, a new introduction from Chad, which gave a pod yield of 3.27 t ha^{-1}. Haulm yields averaged 4.18 t ha^{-1} at Bengou, 4.06 t ha^{-1} at Maradi, and 2.07 t ha^{-1} at Sadoré.

Regional Trials

SADCC/ICRISAT Regional Virginia Groundnut Cultivar Trial

Twenty-three lines were included in this trial which was conducted at Bengou. ICGV-SM 85718, ICGV-SM 85764, ICGV-SM 86725, ICGV-SM 87723, and ICGV-SM 88734 looked promising (Table 19), with pod yields of more than 2 t ha^{-1} and haulm yields about 5 t ha^{-1}. They were harvested in about 100 days and their shelling percentage was above 65%. However, they did not significantly outyield the local controls.

Table 19. Performance of lines in the SADCC/ICRISAT Regional Virginia Groundnut Cultivar Trial, Bengou, Niger, rainy season 1990.[1]

Cultivar	Yield (t ha^{-1}) Haulms	Yield (t ha^{-1}) Pods	Time to harvest (days)	Shelling %	100-seed mass (g)
ICGV-SM 85718	5.29	2.31	100	67.06	61.04
ICGV-SM 85752	6.42	1.09	100	43.53	33.49
ICGM-SM 85764	5.62	2.62	101	65.85	53.81
ICGV-SM 86708	5.44	1.85	99	53.48	66.05
ICGV-SM 86720	5.08	2.23	99	65.75	55.42
ICGV-SM 86722	5.58	1.23	99	47.71	36.01
ICGV-SM 86725	4.38	2.56	99	71.14	63.55
ICGV-SM 86734	6.16	1.47	103	55.17	46.21
ICGV-SM 86737	5.36	1.33	100	51.36	44.68
ICGV-SM 85715	4.97	1.31	101	59.34	47.66
ICGV-SM 86736	6.37	1.21	103	54.18	49.18
ICGV-SM 86741	6.49	1.57	103	53.00	47.45
ICGV-SM 86743	6.65	1.47	103	55.16	43.88
ICGV-SM 87723	5.21	2.18	100	69.56	55.02
ICGV-SM 87733	7.32	1.81	101	46.94	56.88
ICGV-SM 86759	7.11	1.53	103	51.76	42.57
ICGV-SM 87798	7.04	1.65	103	58.80	45.79
ICGV-SM 87805	5.73	1.97	101	67.51	48.94
ICGV-SM 88709	6.59	1.76	103	58.37	52.85
ICGV-SM 88710	5.94	1.66	103	63.29	47.39
ICGV-SM 88711	6.54	1.79	103	57.43	50.55
ICGV-SM 88732	5.56	1.77	101	58.03	55.65
ICGV-SM 88734	5.49	2.26	103	62.63	50.08
Control					
28-206	4.99	2.12	101	64.71	38.72
ICGV 87123	4.93	2.57	100	70.92	44.03
SE	±0.54	±0.15	±0.86	±2.78	±2.49
Trial mean (25 entries)	5.85	1.81	101	58.90	49.48
CV (%)	16	15	2	8	9
Lattice efficiency (%)	123	202	<100	113	109

1. A 5 × 5 lattice with 3 replications; plot size 10 m^2

SADCC/ICRISAT Regional Spanish Groundnut Cultivar Trial

This trial, conducted at Bengou and Sadoré, consisted of 23 entries along with two controls. ICGV-SM 85038, ICGV-SM 86068, and ICGV-SM 86070 were the highest-yielding lines averaged over the two locations (Table 20). At Sadoré, ICGV-SM 85038 gave the highest pod yield (2.92 t ha^{-1}). Haulm yields averaged 5.1 t ha^{-1} at Bengou and 3.03 t ha^{-1} at Sadoré. ICGV-SM 85053 gave the highest haulm yields at both sites with 8.74 t ha^{-1} at Bengou and 5.79 t ha^{-1} at Sadoré.

Table 20. Pod yield (t ha^{-1}) of lines in the SADCC/ICRISAT Regional Spanish Groundnut Trial, at two locations in Niger, rainy season, 1990.[1]

Line	INRAN, Bengou	ISC, Sadoré
ICGV-SM 85001	2.30 (10)	2.58 (3)
ICGV-SM 85038	2.38 (5)	2.92 (1)
ICGV-SM 85053	1.77 (22)	1.39 (25)
ICGV-SM 86039	1.86 (19)	1.81 (20)
ICGV-SM 86043	2.03 (13)	2.46 (6)
ICGV-SM 86053	2.43 (4)	1.69 (22)
ICGV-SM 86070	2.57 (3)	2.32 (9)
ICGV-SM 87003	2.02 (14)	2.13 (14)
ICGV-SM 87009	1.94 (17)	2.59 (2)
ICGV-SM 86015	2.32 (7)	1.73 (21)
ICGV-SM 86021	2.31 (8)	2.57 (4)
ICGV-SM 86022	1.98 (15)	2.26 (12)
ICGV-SM 86051	1.63 (23)	2.35 (8)
ICGV-SM 86052	2.30 (9)	1.67 (23)
ICGV-SM 86054	1.92 (18)	1.58 (24)
ICGV-SM 86066	1.48 (25)	2.07 (16)
ICGV-SM 86068	2.66 (1)	2.45 (7)
ICGV-SM 87039	1.59 (24)	2.31 (10)
ICGV-SM 87040	1.94 (16)	2.06 (17)
ICGV-SM 87064	2.13 (12)	2.06 (18)
ICGV-SM 87079	2.22 (11)	2.05 (19)
ICGV-SM 87080	1.79 (20)	2.10 (15)
ICGV-SM 87082	1.79 (21)	2.18 (18)
Local control		
55-437	2.38 (6)	2.27 (11)
TS 32-1	2.63 (2)	2.52 (5)
SE	±0.13	±0.19
Trial mean (25 entries)	2.09	2.17
CV (%)	11	15
Lattice efficiency (%)	103	135

1. A 5 × 5 lattice with 3 replications; plot size 10m^2.
2. Numbers in parentheses are rankings of entries at each location.

Cooperative Activities

Second Regional Groundnut Meeting for West Africa

We held the Second Regional Groundnut Meeting for West Africa – jointly sponsored by ICRISAT and Peanut CRSP at Sadoré, 11-14 Sept 1990. Its purpose was to follow up on the recommendations made during the first (1988) meeting and to review progress in groundnut research since then. The countries represented were: Bénin, Burkina Faso, Cameroon, Central Africa Republic, Congo, Chad, Guinea, Mali, Niger, Nigeria, Sénégal, Sierra Leone, and Togo. Also represented were:the Peanut Collaborative Research Support Program (Peanut CRSP), Institut de recherches pour les huiles et oléagineux (IRHO), Institut français de recherche scientifique pour le développement et la coopération (ORSTOM), Food and Agriculture Organization of the United Nations (FAO), ICRISAT Center, SADCC/ICRISAT Groundnut Project, and ISC. Fifty-two participants attended the meeting, and 28 papers were presented.

Participants also visited our trials at INRAN Stations at Bengou and Tara. Summary proceedings of the meeting and recommendations will be published in English and French.

Human Resource Development

Two students from the University of Niamey did their degree project work on groundnut agronomy and pathology at Sadoré and Bengou during the 1990 cropping season. A Ph.D student from the University of Höhenheim, Germany, continued his investigation on the effects of phosphorus, micronutrients, and crop residue on the growth and yield of groundnut at Sadoré.

Resource Management Program

Introduction

In 1989, the Resource Management Program (RMP) identified seven coordinated research thrusts (CRT) (ICRISAT West African Programs Annual Report 1989, p. 51); we now report progress on these thrusts: Characterization of Resources, Wind Erosion, Cropping and Production Systems, Crop Residues Management, Agrosilvipastoralism, Soil and Fertility Management, and Technology Assessment. The CRTs reflect our multidisciplinary approach and our efforts to encourage interaction among the 12 disciplines associated in the RMP.

Characterization of Resources

The primary objective of our Resource Management Program is to increase the production of cereal-based production systems and make them sustainable for smallholders. To realize that objective, it is essential to know what resources are available at the farm level and to quantify them with a regional perspective.

Our work on characterization of the climate–described in previous reports–is continuing. Here, we report on the evolution of natural vegetation when protected against external action.

A general overview of the soils of the millet-producing zone and an analysis of the socioeconomic conditions prevailing in some villages in Niger are also presented.

Analysis of Rainfall in the Sahel Using a Modeling Approach

The date of onset of rains in the Sahel varies widely from year to year. Previous analysis of long-term rainfall data carried out at ISC for over 150 locations in West Africa has shown that the length of the growing season could be quantitatively assessed from the date of onset of rains. Computed probabilities of growing-season lengths for a given date of onset of rains were then used in the choice of appropriate cropping systems, and in field trials at ISC, we have shown that with early onset of rains, a relay crop of millet followed by cowpea for hay could be grown successfully. However, there was still the question of whether rainfall at different times during the rainy season depends on the date of onset and whether early onset leads to early cessation of rains.

We attempted to answer these questions using a two-part modeling approach. Long-term daily rainfall data from 1905-1989 for Niamey were used. In the first part, we described the probability of rain throughout the year by fitting a curve to the observed proportion of rainy days. In the second part, the frequency of daily rainfall amounts on rainy days was described using a gamma distribution.

At Niamey, curves were fitted separately to the groups of years corresponding to early, medium, and late onset of rains. The results showed that there were differences in the proportion of rainy days in the early part of the growing season (May-July) for the three groups (Fig. 1). This was to be expected from the way the groups were chosen; however, there was no evidence of differences in the subsequent rainfall pattern in August and September. This supports the view that the pattern of rainfall at the end of the season is independent of the date of onset of rains and hence the probability distribution of growing-season lengths can be computed quite simply from the actual onset of rains in a given year.

Evolution of the Vegetation in a Protected Area in the Sahel

When ICRISAT started in 1981 at the Sadoré site in Niger, a revegetation area of 16 ha was fenced so that we could study the evolution of vegetation on fallowed lands.

In 1984, four 400-m north-south transects and four 400-m east-west transects were laid, constituting a grid spacing of 100 × 100 m. Surveys were made in September 1984 and 1985 in collaboration with the University of Orléans

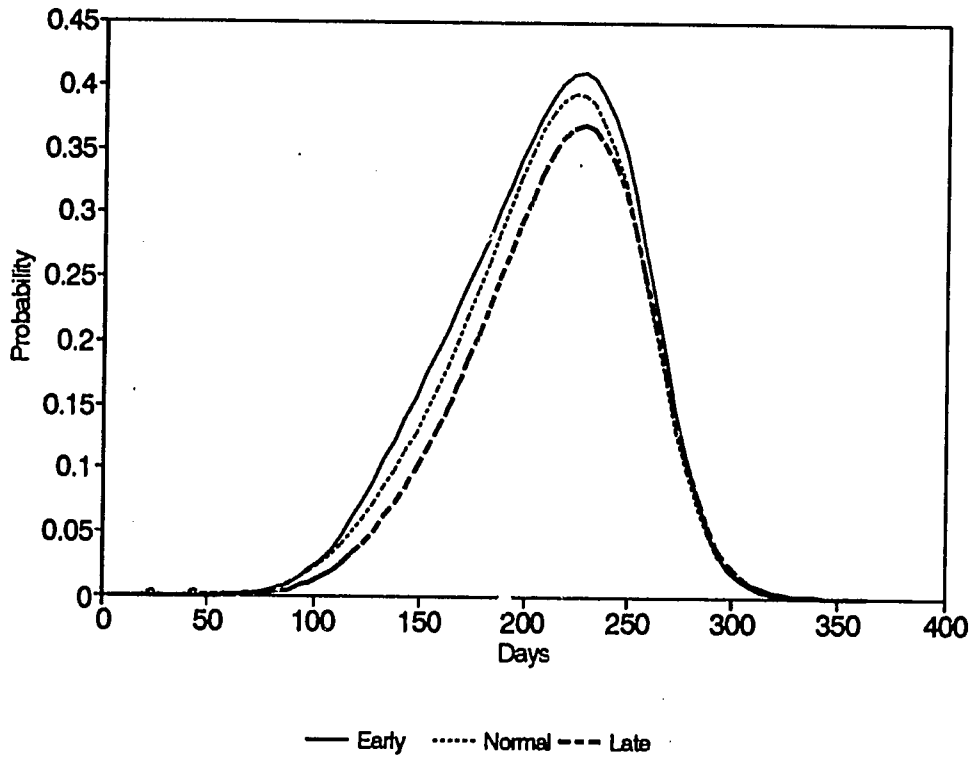

Figure 1. The proportion of rainy days at Niamey, Niger, for early, medium, and late onset of rains groups.

(France), with emphasis on the inventory of shrubs and trees. In September 1989, a third survey was made, using the same methodology, in collaboration with the University of Wageningen (Netherlands).

In 1981, the vegetation was herbaceous; with a few small shrubs and trees, typical of a young fallow. By 1984, the shrubs and small trees were becoming more numerous, particularly *Guiera senegalensis* J.F. Gmel; *Combretum glutinosum* Perr. ex DC., *Balanites aegyptiaca* (L.) Del., and *Piliostigma reticulatum* (DC.) Hochst. *Cenchrus biflorus* Roxb. was the most important of the herbaceous cover, comprising 25.5% of the total number. Annuals dominated, and perennials such as *Andropogon gayanus* Kunth had only 3.7% of that total number. It is important to note that 1984 was a dry year (216 mm of rain).

In 1985, rainfall was much higher (545 mm). This changed dramatically the composition of the herbaceous vegetation: *Cassia mimosoïdes* L. (39.2% of total cover) and *Merremia pinnata* Hochst ex Choisy Mollier (25.2% of total cover) dominated although *C. biflorus* and *A. gayanus* each had about 1% of the total. The cover of shrubs and trees was not as affected by the drought, though their growth was slowed.

Results of the September 1989 surveys showed that the biomass of trees and shrubs increased. The percentage of *C. glutinosum* increased from 10.7% (1985) to 26.1% (1989).

The increase in woody vegetation caused a decrease in the herbaceous vegetation, which dropped from 89.3% of total number of plants in 1985 to 73.9% in 1989. The herbaceous vegetation which covered 95.9% of the total surface in 1985, covered only 77.1% in 1989.

Also, the dominating *C. mimosoïdes* had almost disappeared and was replaced by *M. pinnata*. *A. gayanus* represented 0.73% of the total number of herbaceous plants. Seven new herbaceous species were recorded.

In conclusion, when a fallowed area is protected against animals, humans, and fire, the woody vegetation dominates the herbaceous vegetation. Further, over time, the herbaceous vegetation becomes more diffuse. This study will be helpful in deciding proper management techniques for the protected areas in the Sudano-Sahelian Zone.

Properties of Millet-producing Soils of the West African Semi-Arid Tropics (WASAT)

Soils have been recognized as an important natural resource, and the understanding of their physical and chemical properties will permit their proper utilization, management, and conservation.

Throughout the WASAT, shifting cultivation has been the most widely used land-management system. Basically, it involves the cultivation of a piece of land for a few years, followed by a rest period, whereby the land is allowed to return to native vegetation. This facilitates improvement of nutrient status and soil structure.

The current rapid population growth in the WASAT and the increased demand for cropland have reduced the fallow periods. With continuous cultivation, the productivity of the soil is reduced because of (1) lowering of organic matter below critical levels, (2) physical removal of the soil by wind or water erosion, (3) leaching of nutrients, and (4) exhaustion of soil nutrients by crop removal.

Thirty-one surface (0-20 cm) soil samples were taken from the major millet-producing regions of the WASAT and their chemical and physical properties were studied for physicochemical interactions that influence their nutrient availability.

Physical Properties

The bulk of the millet-producing West African soil is predominantly sand, which influences many of its physical and chemical properties. Surface texture ranges from sandy to sandy loam, In the thirty-one surface soils studied, the total sand content ranged from 71 to 99% (Table 1) with a mean of 87%. These surface soils have friable consistence and they can be slightly hard to hard when dry.

Millet-producing soils have weakly coherent massive to subangular blocky structure, which could be attributed to their low clay content and the predominance of kaolinite in the clay fraction.

These physical attributes of the soils influence their rate of water intake. Their sandy nature and consequently nonplastic wet consistency, coupled with the massive to weak angular blocky structure, promotes good permeability in their undisturbed state, but their permeability has been shown to deteriorate under cultivation. The dune soils of the Sahelian Zone have a very high hydraulic conductivity (150-200 cm day^{-1}) and therefore a rapid internal drainage, but in the Sudanian Zone, with increased clay content and the formation of crusts, the internal drainage is reduced.

The soils have bulk densities ranging from 1.4 to 1.7 Mg m^{-3}, corresponding to a porosity of 36-43% and the available soil moisture can be as low as 0.07 g cm^{-3}. The sandy soils are prone to wind erosion. At the beginning of the rainy season, rains are usually preceded by dust storms, with violent winds that can exceed 100 km h^{-1}. This contributes to erosion and damages the crop seedlings by wind abrasion or by burial under sand.

Chemical Properties

One striking feature of millet-producing soils is their inherently low fertility, which is expressed through their low levels of organic matter, total nitrogen, and effective cation- exchange capacity (ECEC) (Table 1).

The main source of nitrogen is in accumulated organic matter, and the natural low organic matter levels in these soils are reflected in the low total N values. Among the 31 soils studied, total N values ranged from 31 to 1800 mg kg^{-1}, with a mean of 266 mg kg^{-1}.

Cation-exchange capacities of most of the millet-producing soils are generally low, often less than 5 cmol kg^{-1}. This could be attributed to their low organic matter content, the low clay content, and to the kaolinitic mineralogy of the soil system.

Table 1. Means and ranges of selected physical and chemical properties of millet-producing soils of the West African Semi-Arid Tropics (WASAT).

Parameter	Range	Mean
pH:H_2O (2:1 water:soil)	5.2 - 8.2	6.3
pH in KCl	4.0 - 7.5	5.1
Clay (%)	0.7 - 11.7	3.6
Sand (%)	71.3 - 99.0	87.3
Organic matter (%)	0.08- 2.94	0.75
Total nitrogen (mg kg^{-1})	31 -1800	266.0
Exchangeable bases (cmol kg^{-1})		
Ca	0.15- 16.5	2.45
Mg	0.02- 2.16	0.55
K	0.03- 1.82	0.24
Na	0.02- 0.09	0.04
Exchangeable Al (cmol kg^{-1})	0.00- 14.51	1.60
Effective cation-exchange capacity (ECEC)	0.54- 19.20	3.10

Besides being generally deficient in P, these soils tend to react with both native and applied P to form relatively insoluble compounds, rendering P unavailable for plant use. The low content of both total and labile P (Table 2) may be related to several factors, including:

1. parent materials, which are granites, sandstones, and aeolian sands deposited on the continental terminal. These materials are low in mineral reserves and lack minerals that can weather to release inorganic phosphates;
2. low content of organically bound P, which is a consequence of the low organic matter content; and
3. lack of nutrient recycling due to removal of grain and biomass from the fields.

Table 2. Means and ranges of total and labile phosphorus and parameters of P availability in millet-producing soils of the West African Semi-Arid Tropics.

Parameters	Range	Mean
Total P (mg kg^{-1})	25 -349	110
Bray-1 P (mg kg^{-1})	1.0- 30.3	6.0
P-adsorption maxima (ğ g^{-1})	27.8-253.1	95.8
P-fertilizer equivalent (mg kg^{-1})	1.2- 5.0	2.4
External P requirement (mg kg^{-1})	10.5- 56.8	22.9

Uptake of phosphates by crops, including millet, is affected greatly by changes from available to less available or unavailable forms of P in the soil. It is imperative, therefore, to comprehend the mechanisms of P fixation on these soils.

Previous studies on P-sorption characteristics of some major agricultural soils of the WASAT concluded that millet-producing soils among these have low adsorption capacities; hence, small additions of fertilizer phosphate would increase soluble phosphate and give significant crop response. Similar studies were carried out on the 31 surface soils using the method of Fox and Kamprath.

Sorption data were fitted to the Langmuir equation and P-adsorption maxima were calculated from the slope of the resulting curve. Other P parameters determined using the P-sorption data were: P fertilizer equivalent, (which is defined as the amount of P required to raise the level of labile P by 1 mg kg^{-1}), and external P requirement (which is the amount of P to be absorbed to maintain 0.2 mg L^{-1}) in the soil needed to obtain 95% of maximum yield.

A wide range of P-adsorption maxima was obtained on these soils (Table 2). Compared with the Ultisols and Oxisols found in more humid tropical regions, these soils can be considered to have relatively low P-fixing capacities. The low P-sorption capacity is also reflected in the low ranges of fertilizer equivalent (1.2-5.0 mg kg^{-1}) and external P requirement (10.5-56.8 mg kg^{-1}).

Relationships between the P parameters discussed above were studied. P-adsorption maxima were most highly correlated with organic matter, clay, and poorly crystallized Al and Fe phases.

The following model was developed to investigate the simultaneous contributions of soil parameters to P-adsorption maxima:

$$\text{Maximum P sorbed (b)} = 3.85 + 0.17\ \text{PAL} + 0.31(\text{total})\ \text{P},\ R^2 = 0.91$$

where PAL is the poorly crystalline Al phase. PAL alone explained 71% of the variation in P-adsorption maxima of these soils. The increase in R^2 due to the addition of total P indicates that P sorption is associated with factors contributing to high P levels in these soils.

Socioeconomic Characterization

IFPRI/ICRISAT Collaborative Work

The following results are based on longitudinal data from household surveys conducted by ICRISAT from 1982 to 85 and IFPRI from 1988/89 in the Sahelian and Sudanian Zones of western Niger.

Based on both agroclimatic and socioeconomic criteria, four villages were chosen in 1982 for collecting baseline household data and conducting on-farm trials of cropping technologies. A random sample of 25 households was selected in each village, making a total sample of 100 households.

The villages are located in two rainfall zones of western Niger. Two villages (Samari and Sadeize Koira) are in the Zarmaganda (Ouallam arrondissement), a deficit crop production region north of Niamey. This is a Sahelian Zone with average annual rainfall varying from 200 to 400 mm. The other villages (Gobéry and Fabidji) are in the Boboye arrondissement, an intermediate crop production area southeast of Niamey. This is a Sudanian Zone with annual rainfall ranging from 400 to 600 mm.

In the Sahelian Zone, one village (Sadeize Koira) has relatively good access to a major road, and one (Samari) has poor access. In the Sudanian Zone, both villages have relatively good access to a road, but one (Fabidji) has a market while the other does not.

Crop production patterns. Millet dominated the cropping systems in both zones. In the Sahelian Zone sample, 39-45% of the cultivated area was under sole-cropped millet in 1982-85; most of the remainder was millet intercropped with cowpea and sorrel. In the Sudanian Zone, 23-33% was under sole-cropped millet. Again virtually all the rest was under millet/cowpea intercrops with some millet/sorghum intercrops (in favorable micro-environments). Groundnut was an important women's crop in the Sudanian Zone. Both zones had substantial livestock husbandry, as well as migratory and local off-farm activities.

Production technologies in the survey villages were relatively simple: hand tools, family labor, and the occasional use of draft animals. The use of hired labor and purchased inputs was relatively low.

Household millet yields were 175-300 kg ha^{-1} in the Sahelian Zone villages and 225-440 kg ha^{-1} in the Sudanian. There were severe fluctuations in crop output with the 1984 drought: average yields dropped below 100 kg ha^{-1} in the Sahelian and were 100-200 kg ha^{-1} in the Sudanian Zone villages.

In average rainfall years, net returns per hectare in both zones varied between 17 000-27 000 FCFA (about 275 FCFA = US $1) During the 1984 drought, returns fell to 575-1100 FCFA in the Sahelian Zone and 8030 FCFA per

hectare in the Sudanian Zone. Gross returns to household labor were lower in the Sudanian (66-108 FCFA h^{-1}) than in the Sahelian Zone (118-138 FCFA h^{-1}).

Crop and livestock transaction patterns. In transaction and consumption analysis, the most meaningful annual period is from the beginning of the harvest (in calendar year t) through the end of the rainy season (in calendar year t+1). Analysis is oriented around the disposal of the harvest: the sales transfers and home consumption ensuing from a given harvest; or the purchases and transfers received, which supplement the quantity of food harvested. We refer to this period as "harvest year (t-)(t+1)"; e.g., harvest year 1983/84 is the period from harvest 1983 through the rainy season 1984.

The period covered by transactions (purchases and sales) were harvest years 1983/84 and 1984/85. Most households produced enough millet to feed themselves for at least a year after the harvest in both zones in the 1983/84 harvest year; almost none did in the 1984/85 year, because of drought during the 1984 rainy season. Therefore the 1983/84 harvest year is termed the "good" year, while the 1984/85 harvest year is termed the "bad," or "deficit," year.

Yields per hectare were lower in the Sahelian Zone but cultivated land per person was higher. Hence output per person was similar between the two zones, explaining the similar food output sufficiency results between the zones.

Grain and pulse purchases were substantial in the Sudanian Zone in both good and bad years, suggesting the presence of purchasing power based outside of the cropping sector. Purchases were minor in the Sahelian Zone, but food aid receipts (of maize and sorghum) were substantial. This result contradicts the conventional image of the Sahelian peasant household as an autarkic, subsistence household, signifying that food- price policy will have important demand-side effects in rural areas.

Purchases of grains and pulses in physical terms accounted for 40-50% of per capita needs in both good and bad years in the Sudanian Zone; these purchases were only 10% in the Sahelian Zone.

Millet and rice purchases were substantial in the Sudanian Zone in the good year, suggesting the presence of an important demand-side millet market in rural areas.

Maize constituted about 65% of grain/pulse purchases in both zones in the bad year, suggesting important imports to these areas from higher-potential Nigerien cropping zones and coastal countries (Nigeria, Ghana, Bénin). This could have important implications for grain trade between the two areas in the future, particularly with regard to the development of a protected zone for imported cereals in the Sahel.

In money terms, livestock sales were twice as high as crop sales in both zones and in both years. Livestock sales were 50-55% of total sales in the Sudanian Zone and 40-85% in the Sahelian Zone over the 2 years. Presumably, at least part of the livestock sales in the Sahelian Zone represent decapitalization instead of routine sales. This does not appear to be the case in the Sudanian Zone. Cereal sales in the good year constituted about 40% of crop sales in the Sudanian Zone and 80% in the Sahelian Zone; in the bad year, they were 60% and 20%, respectively.

Crop by-product sales (primarily of cowpea hay and some millet straw) constituted nearly 50% of total crop sales in the Sudanian Zone in the good year and in the Sahelian Zone in the bad year; otherwise they comprised about 25%.

Pulses (cowpea and groundnut grain) constituted 10-15% of the crop sales in the Sudanian Zone but virtually nil in the Sahelian Zone. Cereal and pulses sales and gifts did not exceed 10% of output in either zone in either year.

Cereal consumption patterns. This section presents preliminary results concerning rural food-consumption patterns from IFPRI field surveys in the Sahelian and Sudanian Zones of western Niger in the 1988/89 harvest year: September 1988 through August 1989.

Only grain mass (and its caloric equivalent) without bran is reported, as this is generally how the grain is consumed. An across-the-board coefficient of 0.9 was used to convert bran to without-bran mass.

Table 3 shows average daily kilocalorie (kcal) consumption per adult equivalent (AE) by zone and village for 1988/89. Daily caloric consumption from cereals and pulses did not differ greatly over the zones, or between villages per zone. The average consumption in all study villages exceeded the FAO daily caloric requirement of 2280 kcal per AE. The coefficient of variation of these figures was only about 0.3. The adequacy of consumption appeared to be due mainly to the good harvest in both zones in 1988. Cereal consumption was approximately 200 kg per capita for all zones. Pulses accounted for an extremely small share–almost none–of consumption, relative to cereals.

Cereal consumption differed by source (own production, purchases, transfers received) between the two zones. Own production was more important in the Sahelian Zone. In the most isolated Sahelian village, Samari, 98% of cereal calories were from own production; this figure dropped to 87% for village Sadeize Koira, which is only 10 km from the main Niamey-Ouallam road. In the Sudanian market village, Fabidji, as much as a third of cereal calories

Table 3. Annual average consumption of cereals and pulses per adult equivalent (AE) in four villages of Niger, harvest year 1988/89.

Zone and village	Cereal without bran		Cereal and pulses		
	Daily total (kcal[1] per AE)	Daily total (kcal per capita)	Annual total (kg per capita)	Daily total (kcal per AE)	Pulses in total kcal (%)
Sahelian Zone	2550	1910	205	2560	*[2]
Sadeize	2560	1930	206	2570	*
Samari	2520	1890	203	2540	1
Sudanian Zone	2470	1840	197	2490	*
Fabidji[3]	2350	1750	187	2370	*
Gobéry	2660	1980	212	2680	*

1. kcal = kilocalories rounded to the nearest 10.
2. * indicates positive value but <0.5.
3. Cereal consumption is slightly lower in the market village of Fabidji. This may be because tubers and processed cereal foods (e.g., bread, beignets), which are consumed in greater quantities in Fabidji, have not yet been included in the analysis.

came from purchases. The proportion in Gobéry, the nonmarket village, was much lower, indicating the important influence of the level of infrastructural development and income diversification.

Consumption coming from cereal transfers (intrahousehold gifts and food aid) was a very small percentage of total calorie consumption (1-6%). This finding was very similar to the IFPRI/ICRISAT findings from Burkina Faso consumption studies. In the Sudanian Zone, these transfers were most likely intrahousehold gifts (5% of total), whereas in the Sahelian Zone, the transfers (6% of total) were most likely food aid. The composition of transfers in the two zones supports the hypothesis that transfers in the Sudanian Zone comprise mostly intrahousehold transfers of millet, whereas those in the Sahelian Zone are composed mainly of food aid (sorghum and maize).

Between 90 and 98% of cereal calories came from millet in both zones, contrasted with a much more substantial role for maize–from purchases and food aid–recorded in poor harvest years. The market village in the Sudanian Zone had the most cereal diet diversity, but millet still predominated.

Millet was the main cereal purchased in both the Sudanian and Sahelian Zones. Substantial purchases of millet were also observed in the 1982-85 transactions data. The balance of purchases in the Sudanian Zone was of maize and rice.

Average daily calorie consumption changed only slightly over seasons, with a slight decrease in the dry season and a rise in the rainy season. This pattern roughly followed energy expenditure and coincided with findings from the IFPRI/ICRISAT consumption studies in Burkina Faso and elsewhere in the Sahel. The adequacy of the 1988 harvest allowed the consumption level to be maintained at or above requirement throughout the year, mainly from own production.

As expected, the portion of consumption coming from home production was lowest during the rainy season and highest during the cold and hot seasons. Transfers were highest during the harvest season (a time of traditional intrahousehold gift giving) and rainy season (a time when cereal stocks were typically lowest). Calorie consumption from purchases was also fairly high (13%) during the harvest season, indicating that households do not consume own production until stocks are depleted before entering the market.

Wind Erosion

Wind erosion, specially during the early part of the rainy season is one of the major constraints to crop cultivation in sub-Saharan West Africa. Sandstorms that precede rain events have a considerable effect on plant growth from the beginning of the rainy season in May-June until mid-August. Millet in the Sudano- Sahelian Zone is sown after the

first rains in May or June, a period coinciding with damaging storm winds. The damage caused by sand particles ranges from delays in emergence, reduced growth and development, to complete death.

In 1989 (ICRISAT West African Programs Annual Report, pp. 58-61) we reported on the establishment of a new CRT on Wind Erosion. The principal objective of this multidisciplinary effort is to discuss and formulate the research priorities at ISC on all aspects of wind erosion; e.g., quantifying the physical processes involved, assessing the damage to crops, evaluating management techniques to minimize the damage, and screening varieties.

In 1990 we have initiated two new experiments in collaboration with the University of Höhenheim, Germany. The first focuses on the effect of wind erosion on the establishment, growth, and yield of millet plants. The second looks at the potential protection of the millet crop through a windbreak system. This year we report on some of the preliminary measurements made in the first experiment to quantify sand movement over the millet fields and the influence of sand erosion on millet establishment and growth.

Field Design

A millet field of 1.53 ha was divided into 153 quadrats, each measuring 10 × 10 m, and cleaned of all residues before sowing since the main objective was to study the effects of wind erosion. After the first rain of 20 mm on 24 May, millet cv CIVT was sown on a 1 × 1 m grid, on the flat. Because the crop experienced several sandstorms, it was destroyed by 18 June, and resown after a 17-mm rain on 25 June. No fertilizer was applied. After the second sowing, the field was weeded manually three times during the season (after 3, 5, and 9 weeks). Millet pockets were thinned to 3 plants approximately 3 weeks after sowing. Of the 153 quadrats, 40 were selected randomly to monitor the effects of sandstorms on millet establishment, growth, and development.

Monitoring Sandstorm Events

Four anemometers to measure windspeed were installed at a 30-cm height above soil surface. Wind direction data were taken from the routine measurements made at the Agrometeorological Observatory. To quantify the amount of moving sand, a central dust sampling station was installed. Field dust samplers were installed to collect sand at 10-, 35-, 50-, 75-, 100-, 150-, 200-, and 275-cm heights above the soil surface. At each height, wind-eroded soil particles passed through a sampler opening 20 mm wide and 50 mm high. After each erosion event, the eroded soil in each sampler was washed onto a No. 44 Whatman filter paper, which was then ovendried and weighed. An analysis of particle size and nutrient content of the sand captured at different heights is being carried out in the Soil Science Department of the University of Höhenheim, and the results will be reported later.

Measuring the Influence of Sand Deposition on Millet Establishment and Growth

In order to assess the effect of sand on millet establishment, it is necessary to have an estimate of the number of seeds sown in each pocket. This was carried out through random collection of seeds sown in each pocket. After the emergence of millet, the number of millet pockets covered by sand were counted in the 40 quadrats after each erosion event. Pockets were subdivided according to number of visible plants as follows:

- Not covered: >5 plants per pocket.
- Partially covered: 1-5 plants per pocket.
- Totally covered: No plant visible.

We observed millet phenology, dry-matter production, and leaf area at weekly intervals. Final yield and yield components were measured in each of the 40 quadrats.

Effect of Wind Erosion on Millet Establishment

The amount of sand trapped at 10 cm above the soil surface was not closely correlated with the amount of rainfall. On 5 Jul 1990, rainfall was only 2.7 mm, but the maximum sand amount of 383.6 kg m^{-2} was captured at the 10-cm height. On the other hand, a 43-mm rainfall on 29 May was associated with only 63 kg sand m^{-2}.

Storm events with erosive effects took place three times during the first week after the first sowing. The amount of moving sand increased in that time to more than 70 kg m^{-2} at the 10-cm height (Fig. 2). As a result, 60% of all millet pockets were totally covered after a few days, while about 20% were partially covered by sand (Fig. 3a). In addition, the surviving plants were affected by high air and soil temperatures following the sandstorm. Soil temperatures reached a maximum of more than 40°C almost every day during the whole month of June. Some plants began to wilt at the leaf tips. Two weeks after sowing, millet height was not more than 3 cm, although there was no further sand movement in the second week. Further erosion events took place until 25 days after sowing. On 18 June, when only 3% of the monitored pockets were not covered and 90% were totally covered, we regarded the crop as being completely damaged.

The accumulated sand movement during that period reached 384 kg m^{-2} at 10-cm height (Fig. 2). It is important to recognize that most of the erosion events occurred during the first 10 days, when young seedlings are particulary susceptible.

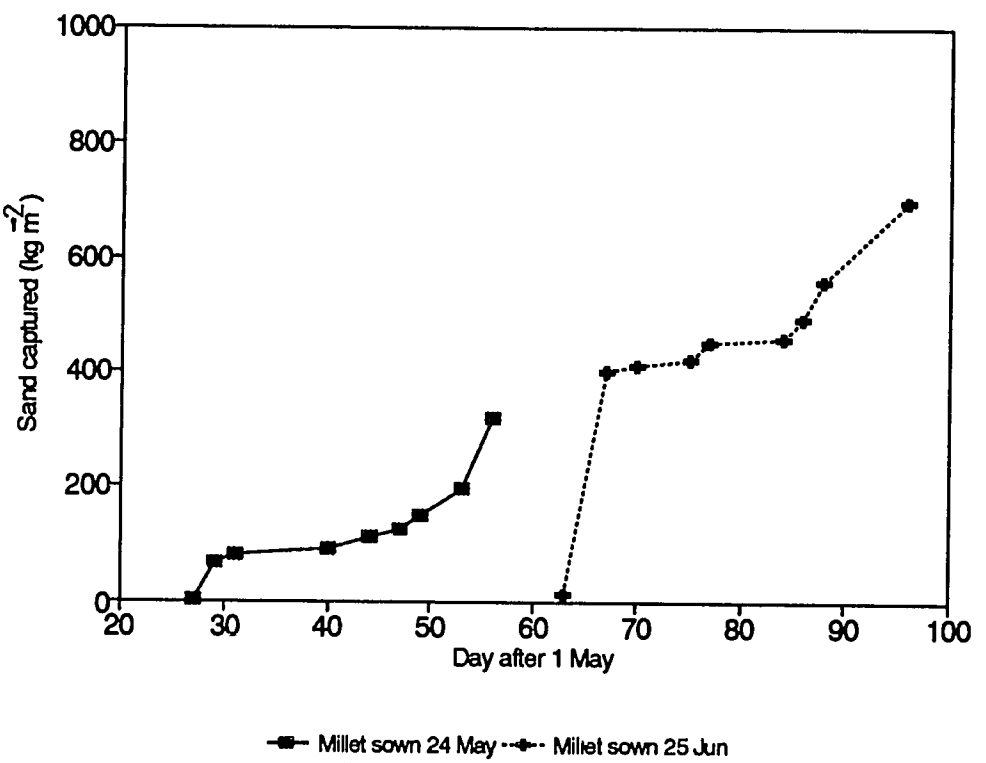

Figure 2. Accumulated sand captured at 10 cm above the soil surface, ISC, Sadoré, Niger, growing season 1990.

After a rainfall of 17 mm, the millet crop was resown on 25 June. The next rain occurred only 15 days after sowing, and it was combined with extremely heavy sand movement; 383.6 kg sand m^{-2} was measured at 10-cm height, which was about 30.3% of the sand trapped during the entire season at that height. About 40% of the emerged millet pockets were totally covered (Fig. 3b). A large proportion of the former partially covered pockets were now covered totally. Following this event, millet in some of the totally covered pockets emerged again. The effect of further erosion events on the millet pockets was less, although the accumulated sand amount reached 946 kg m^{-2} at the 10-cm height.

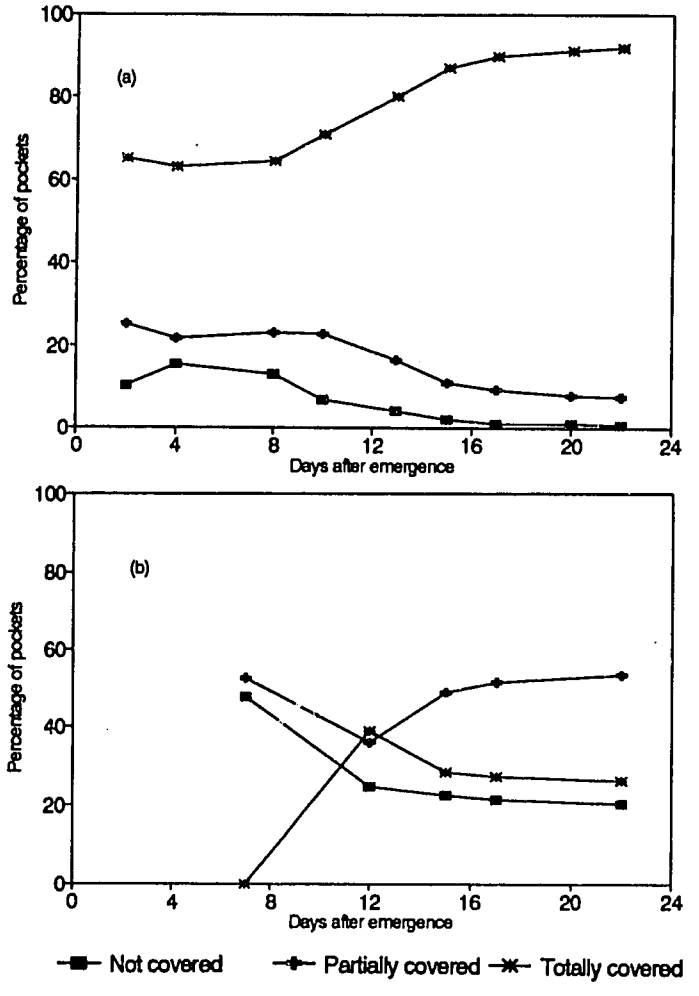

Figure 3. Extent of millet covered by sand particles; (a) millet sown on 24 May; (b) millet sown on 25 June. ISC, Sadoré, growing season 1990.

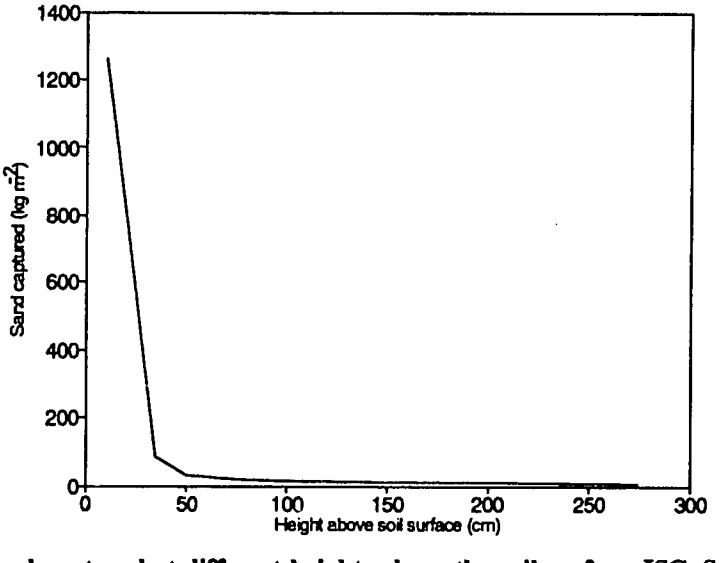

Figure 4. Accumulated sand captured at different heights above the soil surface, ISC, Sadoré, growing season 1990.

The distribution of sand trapped at different heights is shown in Figure 4. The amount of sand trapped decreased exponentially with height above soil surface; Beyond 75-cm height, it was less than 1% of that at 10-cm height, though the distribution at different heights differed with each erosion event.

Effect of Sand Coverage on Millet Growth

Millet growth and development showed a long delay between the not covered and partially covered pockets in nearly all the 10 replications.

Large differences (35%) were observed in leaf development: at 28 days after emergence, the plants not covered by sand had 8 leaves while those partially covered had only 5. On average, plants from the "not covered" pockets had a maximum of 21 leaves while plants from the "partially covered" pockets had 19.

Changes in the leaf area index (LAI) are shown in Figure 5. Maximum LAI is reached 63 days after emergence. In the "not covered" pockets, LAI attained 0.9, but in the "partially covered" pockets it was only 0.4. These differences in the assimilation surface cause very different plant growth patterns, combined with differences in all growth and development parameters.

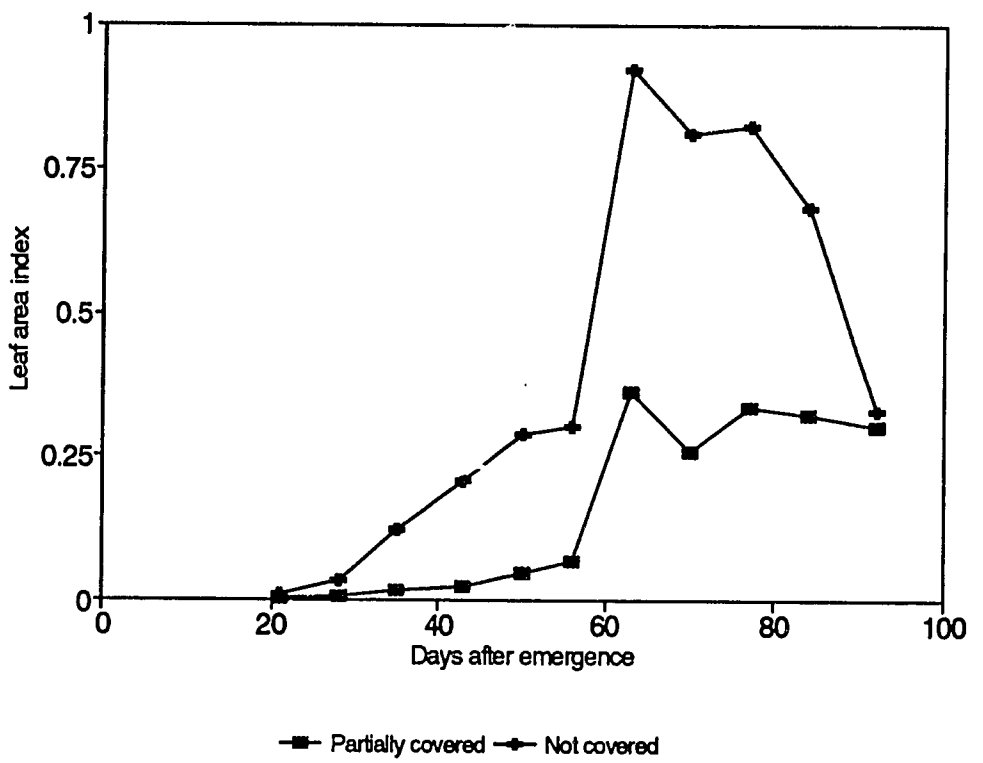

Figure 5. Changes in leaf area index as affected by sand coverage. ISC, Sadoré, growing season 1990.

Above-ground dry matter as affected by sand coverage can be seen in Figure 6. Plants not covered remained unaffected and showed a normal growth curve, with a maximum biomass of 2.87 t ha^{-1}, 77 days after emergence (Fig. 6a), while plants from "partially covered" pockets attained a biomass of only 0.5 t ha^{-1} (Fig. 6b). Final dry matter was 2.46 t ha^{-1} in the "not covered" pockets and 1.46 t ha^{-1} in the "partially covered" pockets.

Millet grain yield of 0.57 (±0.092) t ha^{-1} from "not covered" plants was nearly twice the yield of "partially covered" ones, 0.3 (±0.135) t ha^{-1}. These differences were not due to differences in 1000-grain mass, but panicles from plants of "partially covered" pockets were mostly small, so that grain number was lower than that of the "not covered" plants.

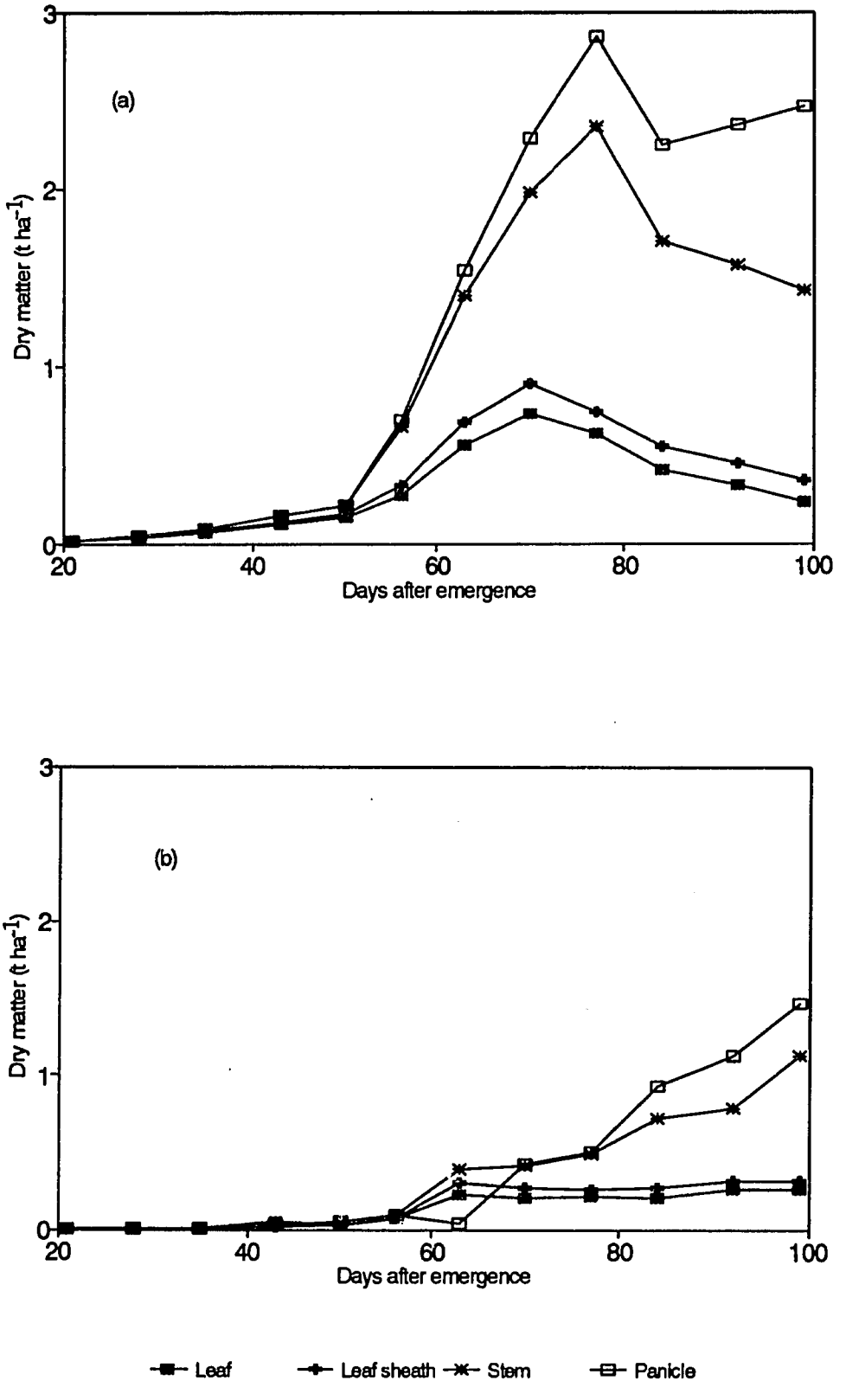

Figure 6. Millet dry-matter production as affected by sand coverage; (a) pockets not covered; (b) pockets partially covered. ISC, Sadoré, growing season 1990.

The preliminary data collected during the 1990 rainy season allowed us to examine critically the extent of damage caused to millet plants by heavy sandstorms. This research will be continued with the objective of understanding the principles of sand transport and characterizing plant damage. The nutrient content of the trapped sand particles will be measured, so that a nutrient balance from an erosion point of view could be calculated.

Potential protection against aeolian erosion could be created by windbreaks or other measures. Crop residues incorporated or left on the soil surface can also reduce sand losses. These aspects will be investigated as a part of the Wind Erosion CRT.

Cropping and Production Systems

The cropping systems of the WASAT are complex. Intercropping of two or more species dominates the cropping patterns in the Sahel, the combination of millet and cowpea now dominating the cropping systems. This dominance is reflected in the nature of the work reported.

We also attached considerable importance to expanding the range of crops, and have investigated how perennial legumes may influence the water use, productivity, and efficiency of the cropping practiced in the millet-dominated Sahelian Zone. The research reported here has also introduced a new concept in the evaluation of crop and variety performance in intercrops.

Also reported is the progress in IITA/ICRISAT collaborative work on cowpea breeding for the Sahelian millet-based cropping zones.

Biomass Production, Yields, and Water-use Efficiency in Pearl Millet/Legume Systems

Fertilizer application has been,and still is studied by various research institutions. Phosphorus is the most limiting nutrient in soils of the Sahel and its use at economic rates such as 24 kg P_2O_5 ha^{-1} (ICRISAT West African Programs Annual Report 1985, p. 67) is strongly recommended. The use of N at the farm level for pearl millet production cannot be generalized for various reasons. It seems preferable to rely on N_2-fixation by legumes, with subsequent transfer to the cereal. This may partly or entirely substitute for N fertilization in intercrops and in relay crops of legume and nonlegume species. Another important aspect of this strategy is the improvement of the nutritive value of the pearl millet straw by the addition of legume hay.

The cereal/legume association, particularly when a perennial legume is associated, allows a better use of the limited resources of water and nutrients. However, proper design and management of the system must be studied to maximize the productivity and to minimize any adverse effects of competition.

At ISC, we started research on systems using pearl millet in association with the traditional grain legume, cowpea (*Vigna unguiculata* L.Wolp.), and with forage legumes, *Sesbania pachycarpa* DC, an indigenous annual legume, widespread in Niger, and *Stylosanthes hamata* (L.) Taub, or stylo, a short perennial legume that originated in Colombia.

The experiments were conducted from 1986 to 1989. Pearl millet cv CIVT was grown either as a sole crop or in association with cowpea, with *S. pachycarpa*, or with stylo, of which two cultivars were used: cv CIAT 147 from the Centro Internacional de Agricultura Tropicale (CIAT) and Verano from Australia (Table 4).

Table 4. Pearl millet/legume cropping systems tested at ISC, 1986-88.[1]

Treatment	1986-88[2]	1989
1	PM	PM
2	PM/C	PM
3	PM/S	PM
4	PM/147	PM
5	PM/V	PM

1. Randomized complete block design with 4 replications.
2. PM = Pearl millet; C = cowpea; S = *Sesbania pachycarpa*. 147 = *Stylosanthes hamata* cv CIAT 147; V = *S. hamata* cv Verano.

In 1989, all plots were sown to sole millet, so that we could evaluate the residual effect of the associations from previous years.

Pearl millet and cowpea were sown at a density of 10 000 hills ha^{-1}. The other legumes were sown in rows at a seeding rate of 4 kg ha^{-1}. Pearl millet was sown with the first planting rains and the legumes sown 2 or 3 weeks after. Before sowing, 13 kg P ha^{-1} had been broadcast in all plots, and N was applied at 15 kg ha^{-1} after the first weeding.

Soil-moisture measurements were made during the 1987, 1988, and 1989 seasons, using a neutron probe. Two neutron probe access tubes 3-m deep were installed in two plots in each treatment. Measurements were taken at depths of 10, 20, and 30 cm, and every 20 cm thereafter, down to 250 cm, every 2 weeks from the start of the rainy season until November.

Climate

Rainfall in 1986 and 1988 was well above the long-term average and the rains were well distributed throughout the whole period. In 1989, rainfall was also above average, and though there was a 3-week drought period in late July, the crops were only slightly affected. The 1987 season was less favorable. It started late (15 July), and rainfall was 20% below the long-term average. A drought period occurred at the end of August and seriously affected the pearl millet crop. Fortunately, rains in the second week of September and in the following 4 weeks helped the pearl millet to recover and some yields, though well below normal, were obtained in most of the treatments.

Biomass Production and Yields

In 1986, grain yields and biomass of pearl millet (Table 5) were high, and there were no significant differences among the various treatments. But legume yields were very low; cowpea gave the highest yield of the three legumes. In 1987, the establishment of pearl millet was very poor; strong sandstorms buried and destroyed the young seedlings. In the sole pearl millet and in the millet/cowpea treatments, no millet yield was obtained (Table 6). In the other associations, pearl millet gave some yield, suggesting that the presence of the legumes provided some protection against the sandstorms. Legume production in 1987 was above that in 1986, as the legumes took advantage of reduced millet growth, particularly stylo cv CIAT 147. Nevertheless, the stand of millet was quite heterogeneous.

In 1988, pearl millet established very well and yields and biomass production were substantial (Table 7). The production of the forage legumes was also high, particularly for the two stylo cultivars. No significant competition effect was noticed between the legumes and the cereal.

In 1989, all the legume plants were removed; pearl millet yields were different among the treatments (Table 8), the highest being for millet following stylo. Both stylo treatments gave significantly higher yields than the other three treatments.

Table 5. Yields of pearl millet, legumes, and total biomass in cereal/legume cropping systems experiments, ISC, 1986.

Cropping system[1]	Cereal yield (t ha^{-1})			Legume yield (t ha^{-1})	Total biomass (t ha^{-1})
	Straw	Panicles	Grain		
PM	2.56	1.51	1.00	-	4.07
PM/C	2.52	1.42	0.94	0.08	4.03
PM/S	2.05	1.22	0.78	0.03	3.30
PM/147	2.84	1.69	1.12	0.02	4.55
PM/V	2.42	1.50	0.96	-	3.92
SE	±0.66	±0.31	±0.21	±0.02	±0.96
CV(%)	53.3	41.9	44.4	105.3	48.3

1. PM = pearl millet; C = cowpea; S = *Sesbania pachycarpa;* 147 = *Stylosanthes hamata* cv CIAT 147; V = *S. hamata* cv Verano.

Table 6. Yields of pearl millet, legumes, and total biomass, water use, and water-use efficiency (WUE) in cereal/legume cropping systems, ISC 1987.

Cropping system[1]	Cereal yield (t ha^{-1})			Legume yield (t ha^{-1})	Total biomass (t ha^{-1})	Water use (mm)	WUE (kg ha^{-1} mm^{-1})
	Straw	Panicles	Grain				
PM	-	-	-	-	-	323	0.07[2]
PM/C	-	-	-	0.18	0.18	328	0.19[2]
PM/S	0.10	0.08	0.05	0.36	0.54	335	2.20
PM/147	0.11	0.06	0.02	1.74	1.91	357	5.72
PM/V	0.30	0.18	0.14	0.18	0.65	344	2.42
SE	±0.08	±0.03	±0.02	-	±0.21	±8.2	±1.33
CV (%)	97	84	97	-	69	3	55

1. PM = pearl millet; C = cowpea; S = *Sesbania pachycarpa;* 147 = *Stylosanthes hamata* cv CIAT 147; V = *S. hamata* cv Verano.
2. Not included in the analysis of variance.

Table 7. Yields of pearl millet, legumes, and total biomass, water use, and water-use efficiency (WUE) in cereal/legume cropping systems, ISC 1988.

Cropping system[1]	Cereal yield (t ha^{-1})			Legume yield (t ha^{-1})	Total biomass (t ha^{-1})	Water use (mm)	WUE (kg ha^{-1} mm^{-1})
	Straw	Panicles	Grain				
PM	1.37	1.11	0.71	-	2.46	519	4.77
PM/C	1.14	0.87	0.50	0.17[2]	2.18	585	2.58
PM/S	1.21	0.94	0.55	0.71	2.81	595	4.99
PM/147	1.25	0.97	0.62	3.04	6.03	634	8.45
PM/V	1.00	0.91	0.51	5.37	7.28	599	12.45
SE	±0.23	±0.17	±0.11	±0.36	±0.38	±14	±1.16
CV (%)	39	37	38	27	18	3	25

1. PM = pearl millet; C = cowpea; S = *Sesbania pachycarpa;* 147 = *Stylosanthes hamata* cv CIAT 147; V = *S. hamata* cv Verano.
2. Not included in the analysis of variance.

Table 8. Yield of pearl millet and total biomass production, water use, and water-use efficiency (WUE) following millet/legume intercrops sown 1986-88; ISC, rainy season 1989.

Cropping system[1]	Yield (t ha^{-1})			Total biomass (t ha^{-1})	Water use (mm)	WUE (kg ha^{-1} mm^{-1})
	Straw	Panicles	Grain			
PM	1.27	0.61	0.34	1.88	440	4.55
PM/C	1.20	0.79	0.45	1.99	449	2.53
PM/S	1.57	0.85	0.49	2.42	436	7.73
PM/147	1.82	1.14	0.67	2.96	439	5.59
PM/V	2.09	1.18	0.71	3.27	433	7.35
SE	±0.51	±0.22	±0.14	±0.71	±4.7	±0.89
CV (%)	45	34	36	40	2	25

1. PM = pearl millet; C = cowpea; S = *Sesbania pachycarpa;* 147 = *Stylosanthes hamata* cv CIAT 147; V = *S. hamata* cv Verano.

Water Use in Cereal/Legume Cropping Systems

In 1987, water use ranged from 323 mm to 357 mm. The highest water consumption was recorded in the pearl millet/stylo (cv CIAT 147) association, which produced much more biomass than the other systems. This treatment also had the highest water-use efficiency. However, as previously stated, the heterogeneity among the plots was very high.

The 1988 results confirmed the advantage of the pearl millet/stylo associations in making better use of the soil water (Table 7). All pearl millet/legume associations consumed more water than the sole millet, but water-use efficiency of the two pearl millet/stylo systems was higher than that of the others.

Positive residual effects of the legumes on the subsequent pearl millet the following year are also reflected in terms of water-use efficiency (Table 8). Though the water consumption was not different among the various crops in 1989, higher biomass production by pearl millet after the association with *S. pachycarpa* and stylo cv CIAT 147 resulted in significantly higher water-use efficiency.

Soil Water Profiles

Figure 7 shows soil-water extraction patterns for the five cropping systems on four selected dates during the 1988 season: at sowing time (18 Jun); when the profile had been well recharged by a good rain (28 Aug); after the harvest of pearl millet (15 Oct); and just before the harvest of the legumes (22 Oct).

The June profile (Fig. 7a) shows that water is extracted from the top 30-cm layer of the soil at the beginning of the rainy season. The August profile (Fig. 7b) shows how well the soil has been recharged with water down to 2.5-m depth.

The 15 October (Fig. 7c) profile shows that there is obviously a difference between the *S. hamata* cv CIAT 147 and the other legumes in terms of root activity and depletion of the profile. The 22 October (Fig. 7d) curves confirm it and also show that cv Verano is still extracting water but to a lesser extent.

In the case of the pearl millet/cowpea intercrop, other findings at ISC show that the choice of the cowpea cultivar and timing of sowing play an important role in reducing these competitive effects. Application of fertilizers (N and P) warrants a concomitant increase in densities of both crops, provided water is not limiting.

In the present experiment, some indications show a slight depressive effect of the legume on the cereal (Table 7) but those are not significant; it is worth mentioning that in 1988, water was not a factor limiting crop production. Other experiments conducted at ISC on the pearl millet/stylo system show that in 1989, there was a significant depressive effect. Current research is looking at management practices, such as cutting the legume during the season, to minimize the negative effect. This also offers the advantage of providing fodder, which can be sold in city markets or stored for the next dry season.

The positive effect of a cereal-legume rotation is well known and has been demonstrated at ISC and other research stations in West Africa. The positive effect of a cereal-legume association on the following year's cereal is rarely obtained. However, in this case a positive effect was observed for pearl millet grown after the *S. pachycarpa* and the stylo intercrop. Those residual effects can be attributed to the N_2-fixation by the legumes and also to the positive effect of the legumes on P availability.

Increased water use and better use efficiency in the association are obvious, particularly in a good year such as 1988. These can be attributed to an increase of production and better exploitation of the profile by two crops with contrasting growth habit and mineral uptake. The legumes compete less with the cereal than other crops and the forage legumes are more efficient than the grain legumes.

Figure 7 shows that both cultivars of stylo exploited the profile better than *S. pachycarpa* or cowpea. This may be because both stylo cultivars are short perennials, while the others are annuals. The root systems of stylo at the end of the cropping season are deeper and better developed, and are still alive after the harvest of the cereal. Of the two cultivars, CIAT 147 seems to be more efficient than Verano.

Finally, the water-use efficiency of the millet grown after the cereal/legume association is improved with all three forage legumes, which have a residual fertility effect and improve the soil nutrient status; fertilizer application to sole pearl millet in earlier experiments gave a similar positive effect, improving water-use efficiency (ICRISAT West African Programs Annual Report 1984, p. 42).

The system associating pearl millet and perennial forage legumes seems promising for the Sudano-Sahelian Zone, and proper management practices have to be examined for minimizing competition between the two components.

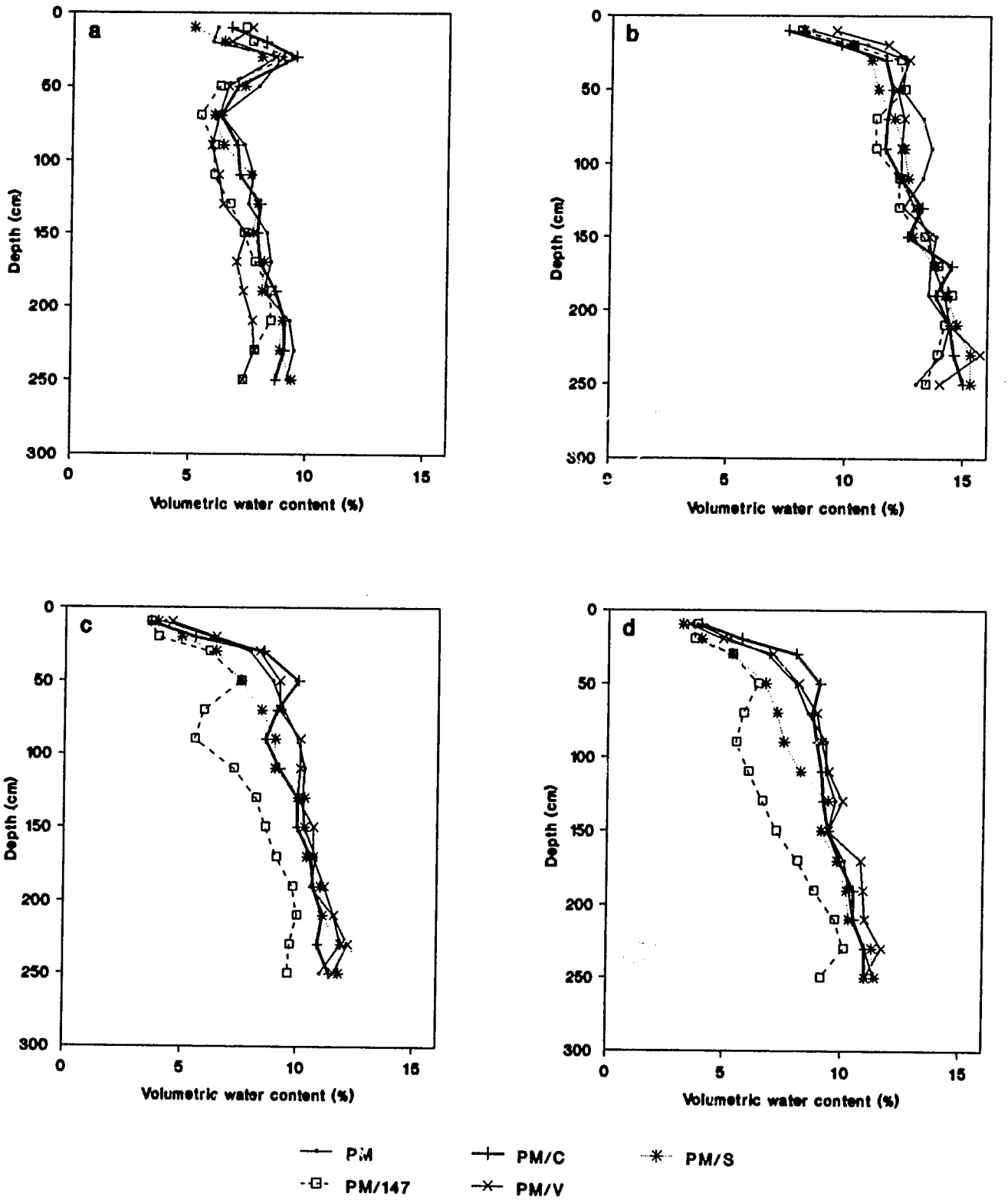

Figure 7. Soil water profiles on four dates in different cropping systems: (a) 18 June; (b) 28 August; (c) 15 October; (d) 22 October. ISC, Sadoré, growing season 1988. PM = pearl millet; / indicates intercropped with C = cowpea; S = *Sesbania pachycarpa;* 147 = *Stylosanthes hamata* cv CIAT 147; V = *S. hamata* cv Verano.

Pearl Millet/Forage Legumes Intercropping

Accessions of forage legumes comprising 64 *Vigna* spp, 60 *Neonotonia* spp, 47 *Cajanus* spp, 34 *Lablab* spp, 11 *Stylosanthes* spp, 8 *Macroptilium* spp, and 2 *Macroptiloma* spp were evaluated at ISC, on a reddish sandy soil (pH = 5). Lines were grown in two 2-m rows replicated three times.

There was considerable variation in the performance of the forage legume accessions. *Neonotonia* spp germinated poorly, whereas *Cajanus* spp, *Lablab* spp, *Macroptilium* spp, and *Macroptiloma* spp germinated well but died shortly after emergence. Only the *Vigna* spp and local *Alysicarpus* spp lines grew well. Seven *Vigna* lines (ILCA # 9326, 9329, 9331, 9354, 9362, 9628, and 11981) rated better than the local cowpea landrace.

Intercropping experiments using local *Stylosanthes fruticosa*, *S. hamata* cv Verano, and pearl millet were continued in 1990. Trials to determine the residual effects of these cropping patterns on subsequent sole-crop millet were conducted in 1990. A randomized complete block design (four replications) with a split-plot arrangement of the treatments was used. Main plots were seven cropping patterns grown previously for 1 or 2 years; subplots were four levels of N (0, 15, 30, and 60 kg N ha^{-1}).

The results showed that stylo intercropping produced more biomass and better residue quality than sole millet. However, stylo intercropping reduced millet grain yield by 15-30%. During the second year of association (millet sown into pre-established stylo), intercrop biomass (4 t ha^{-1}), total N (57 kg ha^{-1}) and P (3.9 kg ha^{-1}) uptake were, on average, 1.4, 4.0, and 2.5 times greater than the values for sole millet. These increases were greatest with an alternate single-row arrangement. Intercrop *S. hamata* herbage yield (2.7 t ha^{-1}) was higher and seed yield (3.3 kg ha^{-1}) lower than herbage (1.4 t ha^{-1}) and seed yields (23.3 kg ha^{-1}) of *S. fruticosa*.

Following 1-/ and 2-year millet/stylo intercrops, nonfertilized millet crop yields and fodder quality increased. After 1 year of association, grain (1.0 t ha^{-1}) and stover (3.1 t ha^{-1}) yields of a nonfertilized sole millet crop were 22 and 17% higher than millet following millet. These yields were comparable to yields of millet following a sole millet crop fertilized with 15-30 kg N ha^{-1}. The grain (1.1 t ha^{-1}) and stover (2.6 t ha^{-1}) yields of millet following 2-year-old intercrops were 35 and 25% higher than yields following sole millet.

Competition Effects Between Pearl Millet and Cowpea

We conducted a 2-year study on two sites (Sadoré and Gobéry) in southwestern Niger to compare the response of six cowpea cultivars to two sowing patterns and two sowing dates relative to millet.

The cowpea cultivars represented the maturity range of cultivars introduced and adapted to the area and included both determinate and indeterminate types growth habits IT 82 D 716 (an erect, determinate cultivar maturing in 65 days), TVX 3236 (a semi-erect cultivar with profuse flowering habit, maturing in about 70 days), B111-2 (a spreading type maturing in 65 days), SUVITA 2 (a spreading type maturing in 75 days, TN5-78 (a spreading type maturing in 75 days, and Sadoré Local (a highly vegetative photoperiod-sensitive, prostrate cultivar, maturing in more than 90 days). The planting patterns compared were single rows of millet alternating with single rows of cowpea, and double rows of millet alternating with double rows of cowpea. The planned sowing dates for cowpea were 1 week and 3 weeks after millet.

Because of variable competitive effects of the cowpea cultivars on millet, these were assessed across cultivars and sowing dates using a millet:cowpea trade ratio (T). This was computed for grain, fodder, and total biomass using the equation:

$$T = C_i/(M_s - M_i)$$

where C_i is the yield of cowpea in the ith treatment, M_s is the yield of sole crop millet, and M_i is the yield of millet in the ith treatment. Thus a high ratio indicates that the competitive effects were balanced by substantial gains in cowpea, while a value of 1 indicates merely substitution of cowpea for millet.

Cowpea cultivars had a substantial effect on the trade ratios for all parameters (Fig. 8) and interaction of T for sowing date and cultivar appeared in the distribution of benefit between fodder and grain. Throughout, TVX 3236 reduced millet yield more than its own yield; at the second sowing date, TN 5-78 had no effect on millet grain yield but was close to being a substitute competitor for fodder. SUVITA 2 and Sadoré Local both had high trade ratios, with considerable sowing-date interaction between grain and fodder. Thus, although there were considerable differences in

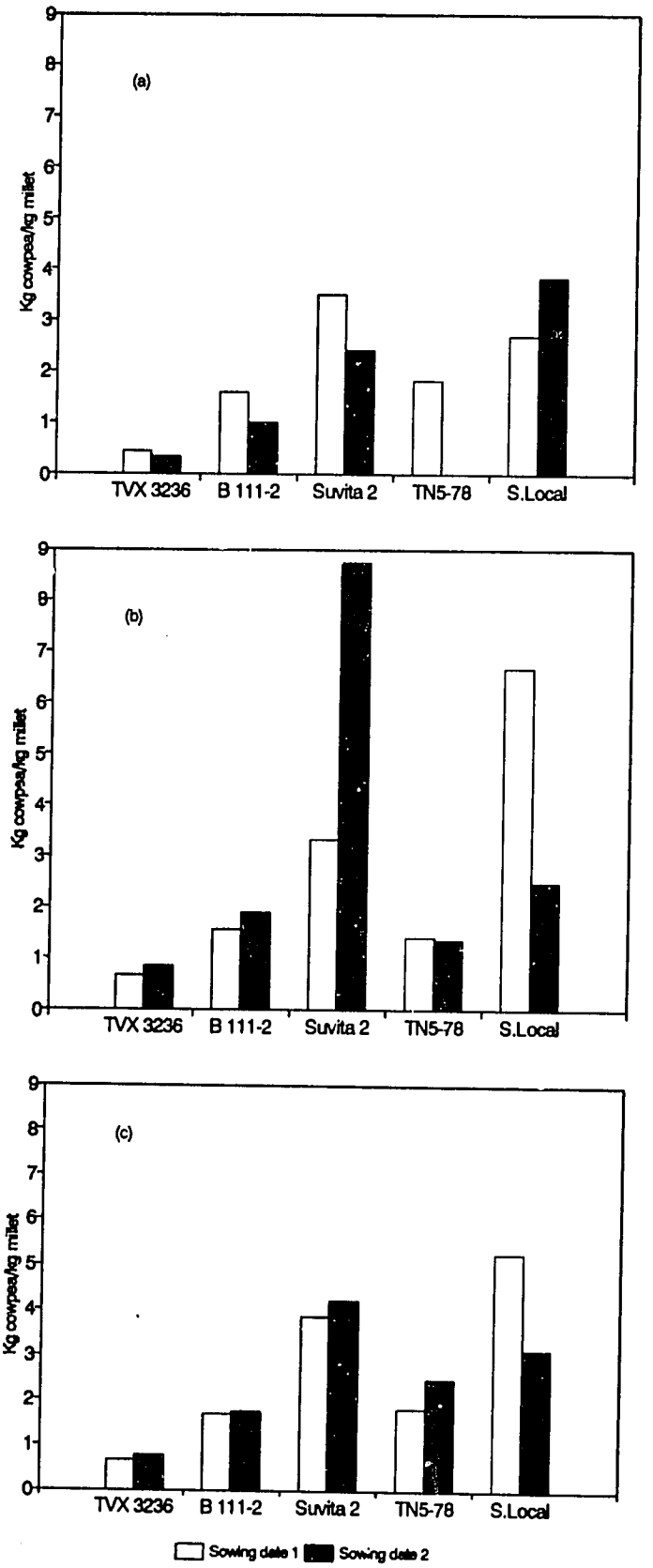

Figure 8. Cowpea:millet trade ratios for (a) grain, (b) fodder, and (c) total biomass of five cowpea varieties intersown on two dates in a millet crop.

absolute yields between these two genotypes, the larger loss of millet yields caused by Sadoré Local offset the benefits.

Cowpea cv TVX 3236 is unsuitable for intercropping because of its relatively large negative impact on millet yield and its own low yield. If the strategy is to ensure maximum productivity of millet grain, then TN 5-78 sown at a later date would be the best choice, since it had no significant negative effect on millet grain, while millet stover was replaced by a higher value of cowpea fodder. On the other hand, if total productivity is the objective, then the earlier sowing of Sadoré Local would be the choice. However, rainfall was above average during the years of these trials and (because this is a late-maturing cultivar) this production system might be relatively unstable, because of the high probability of end-of-season droughts. SUVITA 2, a medium-duration cultivar, would provide a compromise between the least decrease in millet and a very good trade ratio of millet for cowpea. Therefore, cowpea cultivars best suited to intercropping with millet should not strongly compete with the cereal (a staple food crop), but should themselves maintain acceptable yield of both grain and fodder in the intercrop.

One difficulty of selecting cowpea cultivars for intercropping is the impact of competition on the companion crop. In this context, the use of a trade ratio can provide a valuable selection guide to the breeder and a treatment evaluation index for the agronomist. The analysis using trade ratios showed a consistent behavior of all cultivars for biomass, particularly across the sowing dates. This suggests that for these environments, relative sowing date may not be important to cultivar choice. To maximize yields, the earlier sowing of cowpea relative to millet is necessary; however, this would involve major changes in livestock management practices. The greater crop productivity will have to be evaluated in relation to the cost of finding alternative feed for livestock.

Earlier-maturing cultivars to some extent offer an opportunity to manipulate competition gaps. In practice, however, the number of options is fairly limited. New cultivars will need to be screened to determine consistency of performance in the existing cropping systems.

Cowpea Improvement

During 1990, our overall objectives were to develop superior cowpea cultivars with four important attributes: resistance to insects, diseases, and *Striga*;, greater ability to withstand drought and high temperatures; ability to retain leaves until pods are harvested (to provide plenty of fodder); and less competitiveness with pearl millet in intercrops.

Hybridization and Generation Advance

We made a total of 29 new crosses, comprising 4 for bacterial blight, 4 for aphid resistance, 11 for *Striga* resistance, and 10 for adaptation. The F_1 generation was raised during the dry season to produce F_2 plants for evaluation during the cropping season. Bulks and single-plant selections were made in the F_2, F_3, F_4,and F_5 generations.

Resistance to Bacterial and Ashy Stem Blights

The most serious diseases of cowpea in the Sahel are bacterial blight, caused by *Xanthomonas campestris* pv *vignicola*, and ashy stem blight, caused by *Macrophomina phaseolina*. Individually these diseases can cause yield losses of up to 50%. When they occur together, losses can be greater. The best management approach is to exploit resistant cultivars.

Since 1985, bacterial blight has occurred in epiphytotic proportions at the ISC research farm. This has enabled us to identify resistant lines; TN 88-63, TV 4659-03E, IT 81 D 994, and IT 83 S 755-1, IT 85 D 3580-1, and IT 85 D 3580-2 have shown stable resistance and have been used as source of resistance to bacterial blight for incorporation into susceptible but well-adapted local varieties. IT 81 D 994, TV 4659-03E, and IT 83 S 755-1 retain their leaves at maturity of pods, which is an important attribute for dual-purpose cultivars.

Ashy stem blight occurs in association with drought stress and high temperatures. The disease is also frequently a problem after flowering. No stable resistance has been found among the 2000 introduced lines so far evaluated under heavy natural infestation. In 1989, we evaluated 90 local cultivars under artificial inoculation. Only 6 showed no symptoms; 15 showed moderate levels of resistance. In 1990, the 21 lines were retested. The seeds were artificially infected with the *M. phaseolina* pathogen and sown in the field. Results were rather variable and no conclusion could

drawn as to the resistance of these lines. There is a definite need to develop appropriate screening techniques for this disease.

Breeding for Resistance to *Striga*

Striga gesneriodes is an important parasitic weed that causes considerable losses in cowpea yield throughout the Sahel region. Incorporation of resistance into cultivars is the most practical way to control the parasite. We used B 301 as a resistant parent to incorporate resistance to *Striga* into a number of local as well as improved cultivars. Forty-five F_6 derived lines were evaluated in a replicated field test under heavy natural infestation. The same lines were evaluated under contolled infestation. The mean number of *Striga* plants emerged in each plot of resistant lines, and yields of grain and fodder are presented in Table 9.

The inheritance of resistance of *Striga* was studied in crosses involving B 301 and IT 82 D 849 as resistant parents and two susceptible lines, TVU 7607 and Dan Illa. The resistance of parents, F_1, F_2, and BC_1 was evaluated under controlled infestation in plastic bags buried in the soil. The segregation ratios involving B 301 showed a good fit of 3:1 resistant to susceptible plants, while a good fit 3:1 susceptible to resistant plants was obtained in the cross involving IT 82 D 849. This indicated that resistance in B 301 was imparted by a single dominant gene, while in IIT 82 D 849 it was under a single recessive gene.

Table 9. Performance of some cowpea lines bred for resistance[1] to *Striga gesneriodes* at ISC, 1990.

Line	Time to 50% flowering (days)	Time to maturity (days)	Mean *Striga* count[2]	Yield (t ha^{-1})	
				Grain	Fodder
ITN 89 D-76	56	76	2	0.31	0.89
ITN 89 D-77	59	78	0	0.35	1.33
ITN 89 D-78	55	75	2	0.76	1.15
ITN 89 D-79	58	77	0	0.43	1.15
ITN 89 D-80	57	76	1	0.44	0.96
ITN 89 D-81	54	83	0	0.44	0.85
ITN 89 D-82	55	77	0	0.53	0.85
ITN 89 D-84	57	76	1	0.41	0.70
ITN 89 D-85	49	73	0	0.39	0.65
ITN 89 D-87	57	76	0	0.43	0.89
ITN 89 D-88	64	79	2	0.08	1.59
ITN 89 D-93	48	75	0	0.34	0.93
ITN 89 D-96	53	76	2	0.43	0.89
ITN 89 D-100	57	79	0	0.47	0.96
ITN 89 D-101	59	79	2	0.35	1.30
ITN 89 D-103	49	74	0	0.61	0.78
ITN 89 D-111	59	77	0	0.36	1.48
ITN 89 D-114	56	80	3	0.24	1.93
Controls					
TN 88-63	67	85	25	0.18	1.44
Dan Illa	58	82	19	0.50	1.11
TN 5-78	62	83	35	0.52	1.04
SE	±2	±2	-	±0.11	±0.45
Mean (49 entries)	57	79	-	0.33	1.00
CV (%)	6		-	57	43

1. F_6 derived lines involving *Striga*-resistant cv B301 as resistant parent.
2. No. of emerged *Striga* plants per plot.

Breeding for Resistance to Aphids

Aphis craccivora is an important pest of cowpea in the Sahel, particularly when there is drought. A number of resistant cultivars are available. Cultivar IT 84 E 1-108 as a source of resistance was crossed with a susceptible local cultivar (Sadoré Local). Among the 45 F_7 derived lines evaluated under artificial infestation in an insect proof cage, 9 were identified as resistant (Table 10). We also evaluated 64 local cultivars from Niger for aphid resistance, none was found to be resistant.

Table 10. Field performance of lines derived from a cross involving an aphid-resistant cowpea line (IT 84 E 1-108) and a susceptible local cowpea cultivar (Sadoré Local), ISC, 1989.

Line	Reaction to aphids	95% Maturity	Yield (t ha^{-1}) Grain	Fodder
ITN 89 D-7	R[1]	78	0.31	2.00
ITN 89 D-10	R	80	0.21	0.74
ITN 89 D-16	R	89	0.03	1.70
ITN 89 D-17	R	94	0.06	2.44
ITN 89 D-20	R	81	0.06	1.30
ITN 89 D-26	R	84	0.10	1.22
ITN 79 D-42	R	97	0.06	2.11
ITN 89 D-52	R	77	0.26	1.81
ITN 89 D-63	R	78	0.10	2.41
Control				
Vita 7	S	82	0.19	1.48
Sadoré Local	S	99	0.19	3.03
IT 84 E 1-108 AR	R	73	0.28	0.52
SE		±1.4	±0.043	±0.41
Mean (49 entries)		84	0.11	1.78
CV(%)		3	66	40

1. R = resistant, S = susceptible

Yield Trials

Varietal selection and evaluation were major areas of research in the breeding program. This involves the introduction of exotic material and incorporation of useful traits into adapted cultivars. Newly developed cultivars need to withstand the harsh environmental conditions of the Sahel. The objective of the yield trials was to screen newly developed advanced breeding lines for disease resistance, field performance for yield, and adaptation. We conducted two adaptation trials:

Adaptation Trial 1. This trial consisted of 49 entries and was sown on 6 June 1990. Grain yield was generally low, ranging from 0 to 0.78 t ha^{-1} (SE ±0.09), but fodder yields ranged from 0.5 to 3 t ha^{-1} (SE ± 0.31). ITN 89 D 53, ITN 89 D 60 and ITN 89 E 16 were promising in terms of grain production. ITN 89 D 4 produced the highest fodder yields (3 t ha^{-1}); ITN 89 D 1 and ITN 89 D 27 produced reasonable yields of both grain and fodder.

The same trial was sown on 4 Aug 1990, so that flowering and pod-filling stages would coincide with the end of the rainy season. No rainfall was received throughout the flowering and pod-filling stage. Grain yield was generally higher than in the first sowing, but fodder yields were extremely low due to leaf senescence resulting from drought

stress. Lines such as ITN 89 D 23, ITN 89 D 53, and ITN 88 DM 667 produced 0.54, 0.60, and 0.66 t ha^{-1} (SE ±0.08) of grain yield, respectively.

Adaptation Trial 2. This trial consisted of 64 entries representing advanced breeding lines developed at ISC, and some introductions from IITA, Nigeria, and IITA/SAFGRAD, Burkina Faso. The trial was sown on 4 Aug 1990. Vegetative as well as reproductive phases experienced severe drought stress. Yields of both grain and fodder were generally low; ITN 87-60-16, and ITN 87-60-17 produced the best grain yields.

Crop Residues Management

Crop residues play an important role in the region. For protection against wind erosion, spreading crop residues on the fields is strongly recommended. Farmers also use them for many other purposes; for instance mat-making, fuel, and feed. We present below an evaluation of millet crop residues for their nutritive value.

A collaborative ILCA/ICRISAT trial was conducted to determine the yields and the feeding value of millet stover parts at various levels of fertilizer N and P: (15-4.4, 45-4.4, 15-17.4, and 45-17.4 kg ha^{-1}). Total grain and stover yields were estimated from two randomly placed 10 × 10 m quadrats in each of three replications per fertilizer level. Two millet stands per quadrat were divided into grain, threshed panicles, bran, barren panicles, nonproductive tillers, and the leaves and stalks associated with upper, middle, and lower stover fractions based on equal divisions of total stalk height. Plant part samples within quadrats were bulked and analyzed for dry matter (DM), nitrogen (N), and phosphorus (P) contents.

Total stover produced was made up of: 7.3% barren panicles; 22.4% upper one-third of the plant; 25.3% middle one-third; 37% lower one-third; and 7.3% nonproductive tillers. Higher harvest index (HI), and proportionally less threshed and barren panicles, were associated with the highest fertilizer level (45-17.4 kg N-P ha^{-1}). The ratio between millet grain, threshed panicles, and bran was estimated to be 1.00:0.52:0.30. Millet stover contained, on average, 16 kg N and 2.2 kg P ha^{-1}; barren panicles contained approximately 14% N and 24% P; upper stover 27% N and 32% P; middle stover 23% N and 14% P; lower stover 26% N and 21% P; and nonproductive tillers 10% N and 9% P.

Agrosilvipastoralism

The Agrosilvipastoral CRT of the Resource Management Program was established in June 1989. It is responsible for coordinating research at ISC on the forest/cropland/livestock systems of the Sahel. As such, it overlaps but does not include in toto the work of the agroforestry and agronomy subprograms and the ILCA team at ISC. The specific research tasks of the thrust are as follows:

- Qualitative studies of browse and forage species;
- Quantitative studies on the supply of browse and fodder resources;
- Incorporation of browse and fodder species into cropping systems and improvement of these species;
- Nutrient cycling in the forest-cropland-livestock continuum; and
- Marketing and economic potential of browse and fodder.

Effect of Arboreal Shade on Growth of Pearl Millet

The changes in physical environment under a typical *Faidherbia albida* tree were monitored between May and September 1990. The effect of the tree on soil temperature was monitored with thermocouples and a CR-21X data logger. The trunk of the tree was used as a center of three transects radiating north, southeast, and southwest. Thermocouples were buried at 2 and 10 cm inside (2 m from the trunk) and outside (5 m from the trunk) the canopy at 2- and 10-cm depths. Soil temperatures were read every 20 s and averaged over every 15-min interval. Changes in incident solar radiation under and outside the canopy were measured using a Delta T radiometer.

The shade created by the tree resulted in substantially lower soil temperature. Soil temperatures outside the canopy rose above 50°C on 22 May, the day before the first rainstorm of the year. Temperatures inside the canopy averaged about 10°C lower between 1200 and 1700h (Fig. 9a). On the day after this 20-mm rainstorm (24 May), soil temperature

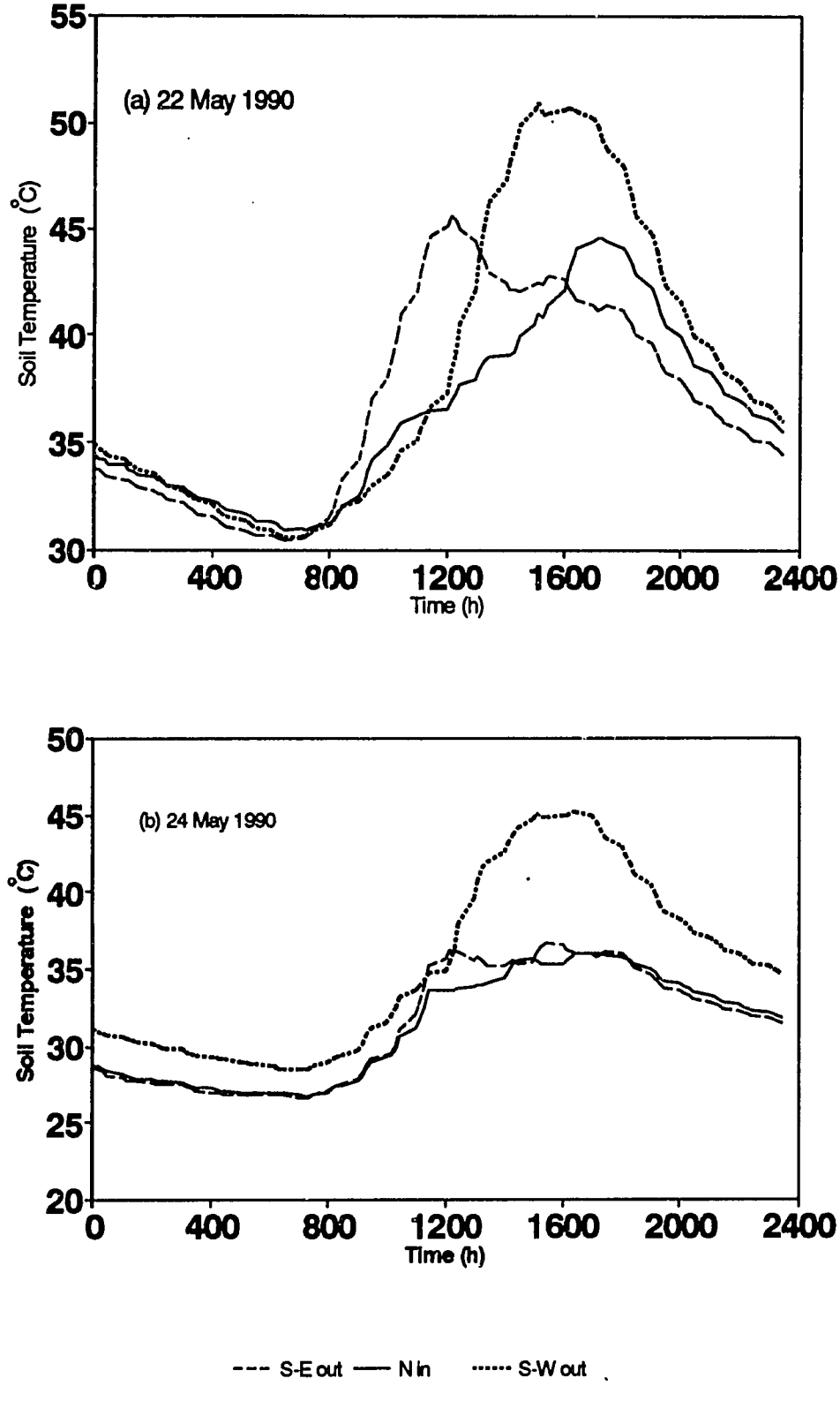

Figure 9. Soils temperature at 2-cm depth inside and outside the canopy-shaded zone of a 56-cm diameter *Faidherbia albida* tree: (a) 22 May, 1990, before a rainfall event; (b) 24 May 1990, the day after the rainfall event.

outside the canopy was about 45°C (Fig. 9b). Inside-canopy temperature never rose above 35°C on this day and throughout the week-long interval until the next rain event.

In a companion experiment, a 1-m-tall fence made of millet stalk mats was erected in a north-south direction. The fence created shade of varying width and duration, depending on the time of day. On 18 May, pearl millet was sown in rows perpendicular to the fence and germinated with 40 mm of irrigation. Soil surface temperatures were measured at 2-h intervals, at stations located every 0.5 m from the fence. Two millet varieties were used and each plot was replicated four times. The millet was allowed to grow for 7 weeks and then the shoot mass harvested, oven-dried, and weighed.

Soil surface temperatures followed patterns much like those recorded under the tree (Fig 9). Both millet varieties responded similarly to the presence of the fence. Millet survival and growth decreased linearly with distance from the fence and inversely with the mean soil surface temperature (Fig. 10). Mortality reached nearly 100% 3.5 m from the fence.

These results suggest that the lower soil surface temperatures induced by the shade is a major benefit derived from the *F. albida* tree. This hypothesis is supported by the fact that high temperatures in the vicinity of the stems of cereals may cause injury to the phloem and reduce or prevent translocation of assimilates to the roots.

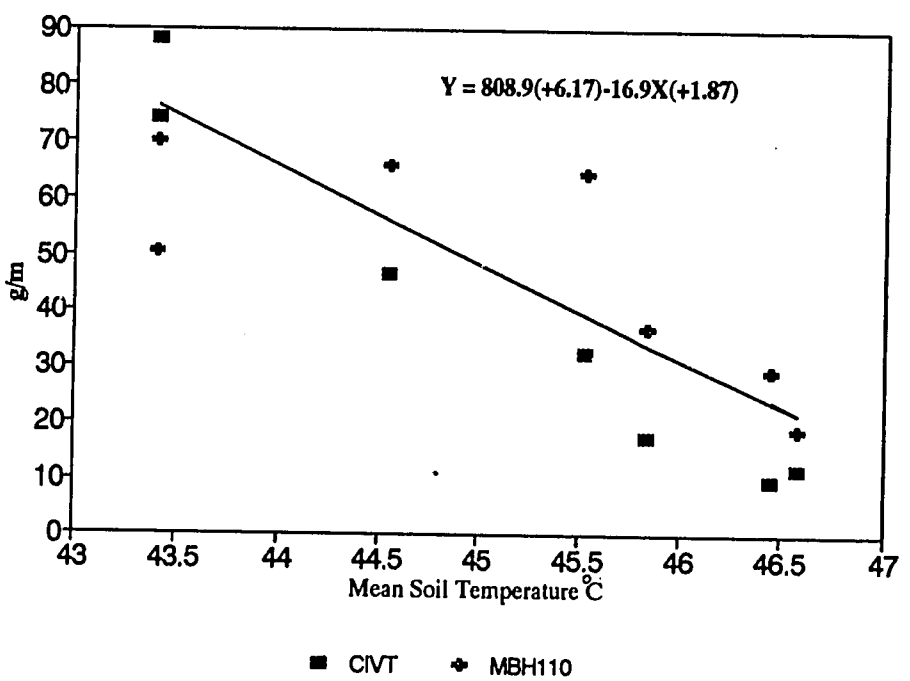

Figure 10. Early growth response of millet varieties to mean soil surface temperatures at ISC, Sadoré.

Feed Evaluation and Feeding Systems

Experiments were conducted by ILCA scientists at ISC to determine the intake and nutritive value of indigenous feeds that can be used in supplementing pearl millet stover and low-quality pastures, especially during the dry season.

In one experiment, leaves from indigenous browse species (*Ficus gnaphalocarpa, Mitragyna inermis, Anogeissus leiocarpus,* and *Pterocarpus erinaceus*) were collected and dried. Eight mature male sheep were arranged in a change-over design with four treatments (browse species), and voluntary intake measurements were recorded. The measurements showed that intake of leaves from *P. erinaceus* and *F. gnaphalocarpa* was high (3.16 and 3.03% of liveweight; 73 and 71 g daily intake per kg metabolic bodyweight, respectively), *M. inermis* was unpalatable (1.21%;

leiocarpus was intermediate (2.31%; 54 g). Intake of millet leaves was 1.99% (47 g). Feeding palatable browse species (*P. erinaceus* and *F. gnaphalocarpa*) at 1% of liveweight in *ad libitum* millet-leaf diets increased total dry-matter intake compared with pure millet-leaf diets, with minimal substitution effect.

In another experiment, the potential degradability of dry matter, organic matter, and N in samples from late, normal, and early (green) harvested millet stover (leaves) and millet ratoons was evaluated with the nylon-bag technique. Samples were weighed into nylon bags and incubated for determined intervals (9, 32, and 73 h) in the rumen of fistulated sheep. The potential dry-matter degradability of the different millet leaves was about 67-68% and that of millet ratoons, 65%. The nylon-bag technique also allowed the estimation of time needed for digestion of half of the feeds (t_{50}): the millet leaves took 18.5- 21.5 h, while millet ratoons took only 13 h to digest.

In a collaborative ILCA/ICRISAT trial, the diet intake of free-grazing sheep and goats was studied over a 4-month period (Nov 1989-Mar 1990). The trial was located on a 1.21-ha area of millet stover with strips of six browse species (*Bauhinia rufescens, Ziziphus mauritiana, Acacia nilotica, A. senegal, A. trachycarpa,* and *Faidherbia albida*) and *Andropogon gayanus* and *Azadirachta indica* planted as windbreaks. Average animal liveweights at the start of the trial were 29.1 kg for sheep and 19.8 kg for goats. Bite counts were recorded twice weekly, and together with DM disappearance, selectivity ratios (SR) for each plant species were calculated (SR of +10 indicates maximum selectivity, -10 total avoidance, and +1 and -1 selection in proportion to availability).

Goats predominantly browsed (average SR = 4.9 for 16 weeks), whereas sheep almost exclusively grazed millet stover and weeds (SR = 0.48). *A. trachycarpa* was the least selected browse by goats, followed by *A. indica* and *B. rufescens*. Weeds were heavily grazed by sheep and goats during the first 3 weeks of the study (SR = 8.9). Weeds continued to be selected by sheep up to their total disappearance in the ninth week of the study. Millet leaves and *A. gayanus* were important components of both sheep and goat diets during the latter weeks of the trial. Patterns of weight change were similar for both animal types: sheep attained maximum weights at 12 weeks (33.3 kg) and goats at 10 weeks (22.5 kg). At the end of the trial (16 weeks) sheep weighed 32.8 kg and goats 21.7 kg.

Village Reconnaissance Surveys

On-farm surveys based on interviews and informal observation were conducted in villages in different parts of Niger to obtain information on animal management practices and utilization of crop and animal by-products. In general, two systems of animal production—extensive and semi-intensive—were identified. In villages in the arrondissements of Ouallam and Say, extensive grazing of crop residues, indigenous forages, browse, and pasture species appeared to be the main method of animal feeding. Farmers used a combination of own-farm and communal grazing. Farmers obtained manure by paddocking animals in fields. Cattle and donkeys were used for transportation, but not for tillage. In villages in the arrondissements of Birni N'Konni and Gaouré, farmers practiced a semi-intensive system of animal production. Grazing period per day was found to be shorter, and there was a greater reliance on own and purchased crop residues than in the other two areas. The use of animal traction for land preparation and weeding was more widespread here. Hand spreading of manure collected from the compound and taken to the fields by animal-drawn carts was found to be common. In both systems, the majority of the animals reside in and around the villages for most of the year.

Nutrient Cycling by Ruminants

In 1990, ILCA staff started a project on nutrient cycling by ruminants. The objectives of this project were:

- to estimate the amounts, spatial distribution, and seasonal variability of manure dry matter (DM), nitrogen (N), and phosphorus (P) output by cattle, sheep, and goats, and to assess the sustainability of animal-mediated nutrient transfers (direction and magnitude) between grazing and croplands,
- to compare the relative effectiveness of cattle and sheep manure in improving millet yields and to determine the effect of various manuring practices on soil physical and chemical properties.

During 1990, a 4-year field trial was initiated at ISC. Treatments included cattle and sheep manure, with seven manure application methods. Treatments were assigned factorially to subplots of 4 × 4 m arranged in a randomized complete block design and replicated six times. Controls (no manure) were included in each replication.

Crop response to manure was low at all locations in 1990 due to inadequate rainfall. On-station total yields (millet plus weeds) in manured plots (5 t ha^{-1}) were, on average, 68% greater than in nonmanured plots. Responses to sheep and cattle manure were linear up to applications of 6.5 t ha^{-1}, with each unit of manure addition producing an average of 0.18 units of yield. Yields in plots receiving manure and urine (5.6 t ha^{-1}) were 52% greater than in plots receiving manure only.

Studies were initiated in June 1990 with 37 farmers in 7 villages covering 3 rainfall zones (600, 425, and 350 mm annually) in Niger. A survey that included field measurements was made to define cropping patterns and manure management practices, manure types and amounts applied, and methods of application. Amounts of manure were estimated visually in 1-m^2 quadrats placed randomly along two transects in each field. For cattle, droppings were ranked by comparison with an established "average dropping size" (which is given 100%). Sheep and goat droppings were counted together and as "groups," with each group comprised of 25 individual feces. Errors associated with estimated and true dry-matter mass were determined by having enumerators estimate the sizes of 25 cattle feces, and the number of "groups" of sheep and goats of known mass placed in 25 quadrats of each manure type. Millet grain and stover, and weeds were harvested from five randomly placed 2.5 × 2.5 m quadrats in one manured and an adjacent nonmanured field for each farmer.

Average cultivated areas for farmers in the dry zone were 9.2 ha, of which 2.8 ha were manured. In the medium-rainfall zone, the values for cropped and manured areas were 6.3 ha and 3.3 ha, and in the wet zone, 3.2 ha and 0.93 ha, respectively. Manure DM (3800 kg ha^{-1}), N (45 kg ha^{-1}), and P (5.7 kg ha^{-1}) application rates were greatest, however, in the wet zone, followed by the medium-rainfall zone (1700, 23, and 3 kg ha^{-1}), and least in the dry zone (1300, 22, and 2.7 kg ha^{-1}). Small-ruminants manure was prominent in the dry zone, with an equal distribution of small ruminants and cattle in the other two zones. Average total biomass production (millet and weeds) in manured areas of the dry (2.6 t ha^{-1}), medium (3.3 t ha^{-1}) and wet (5.2 t ha^{-1}) zones were 26, 10, and 18% greater than in nonmanured areas. In one village located in the dry zone, however, manuring reduced total yields significantly, perhaps reflecting the increased risk of excessive manure application in low-rainfall areas.

Soil and Fertility Management

The traditional agricultural system in tropical West Africa is shifting cultivation, whereby cleared land is cultivated for 1-3 years, then fallowed for 4-20 years to restore soil fertility.

Today, with increasing population, fallow periods have decreased or ceased, and more marginal land is brought under continuous cultivation, increasing soil degradation and lowering soil fertility, and, consequently, lowering crop yields.

To alleviate the food shortage and resource degradation problems in the Sahelian Zone of the WASAT, the soil fertility subprogram has concentrated its research efforts on developing sustainable soil management technologies, which will enhance food production and preserve the natural resource base.

Changes in Soil Chemical Properties

Surface (0-20 cm) samples of soils with different cropping histories were taken at the ICRISAT Sahelian Center and analyzed. Table 11 provides clear evidence of the degradation of soil fertility as a result of cultivation. A comparison of treatment 2 (fallow) and treatment 1 (continuous cultivation from 1982) shows that cultivation, even without use of chemical fertilizers, has a detrimental effect, increasing acidification and lowering base saturation. For the low buffering capacity of those sandy Sahelian soils, the maintenance of organic matter is crucial to maintaining soil productivity. Organic matter recycling with application of crop residue or manure helps maintain the soil pH and exchangeable bases (treatment 2 versus treatment 9, treatment 2 versus treatment 5).

Table 11 gives some relationships among properties of soil under different management practices. Organic matter alone explains 54% of the variation of the effective CEC and the correlation between total N and organic matter is highly significant ($r = 0.82$). Continuous cultivation reduces the organic matter in the soil, reducing effective CEC and pH and base saturation.

From all the sites where soil samples were taken, pearl millet yield potential was also estimated, and models developed to assess the relationships between the soil chemical properties and the yield potential. Organic matter, total N, and available P (Bray-P1) are the variables to which millet yield is most responsive. In the first model, organic

Table 11. Chemical properties of soils with different cropping histories.

Cropping history[1]	pH (H_2O)	Organic matter (%)	Bray-P (mg ka^{-1})	Total N mg ka^{-1}	Exchange-able acidity (cmol[+] kg^{-1})	Exchange-able base (cmol[+] kg^{-1})	Effective CEC (cmol[+] kg^{-1})	Base satu-ration (%)	Al satu-ration (%)
Continuous cropping since 1982 No addition of fertilizers	4.71	0.264	3.87	96	0.575	0.315	0.897	34	46
Fallow	5.45	0.404	3.18	195	0.220	0.813	1.032	79	12
Continuous cropping since 1983 with addition of 30 kg N^{-1} as urea, 30 kg P_2O_5 ha$_{-1}$ as SSP each year	4.71	0.251	12.24	117	0.165	0.432	0.975	44	38
Continuous cropping since 1983 with addition of crop residue 30 kg N, and 30 kg P_2O_5 ha^{-1} each year	5.25	0.358	14.98	166	0.543	0.873	0.752	52	33
Continuous cropping since 1982 with addition of 30 kg N as urea and 500 kg of crop residue from 1987 each year	5.10	0.199	3.71	98	0.365	0.392	0.752	52	33
Continuous cropping since 1982 with addition of 30 kg N as urea, 40 kg P_2O_5 as SSP each year, and 2 t ha^{-1} of crop residue from 1987	5.03	0.291	8.82	155	0.345	0.490	0.835	60	21
Continuous cropping since 1982 with addition of 40 P_2O_5 ha^{-1} each year and 2 t of crop residue ha^{-1} from 1987	5.41	0.289	10.51	149	0.258	0.548	0.832	65	16
Continuous cropping since 1982 addition of 30 kg N ha^{-1} as urea and 40 kg P_2O_5 ha^{-1} as rock phosphate each year and 2 t ha^{-1} of crop residue	5.31	0.303	5.32	112	0.262	0.487	0.737	66	16
Continuous cropping since 1984 with 20 t ha^{-1} of FYM every 3 years	5.47	0.337	14.55	232	0.160	0.877	1.037	85	15
Contnuous cropping since 1987 with addition of 5 t ha^{-1} of FYM t ha^{-1} of crop residue and 40 kg P_2O_5 ha^{-1} as SSP	5.87	0.403	14.81	267	0.065	1.520	1.585	96	0
SE	±0.079	±0.019	± 1.23	±0.53	±0.03	±0.0028	±0.0027	±3.41	±2.82
CV (%)	3	13	25	14	22	6	6	10	29

1. SSP = single superphosphate; FYM = farmyard manure.

matter and available P explain 72% of the variation of the yield potential, in the second model, available P and total N explain 84% of the variation. With 5 mg kg^{-1} available P content and 100 mg kg^{-1} total N, production can be expected to be 130 kg ha^{-1}, but with 10 mg kg^{-1} available P and 200 mg kg^{-1} total N, a yield of 1375 kg ha^{-1} can be obtained.

Phosphorus Sufficiency Levels for Pearl Millet Production

This study was aimed at selecting the soil-test method best suited to determining P availability in the sandy soils of the Sahel. Representative soil samples (0-20 cm) were taken from each plot before sowing and analyzed for available P content using five soil-test methods: Bray-1, Bray-2, Mehlich-1, Olsen, and water extractable P (WEP). Phosphorus sufficiency levels were estimated. Three types of P fertilizers were previously used: Tahoua and Parc-W rock phosphates (TRP and PWRP), partially acidulated PARP Tahoua and Parc-W rock phosphates (PAPWRP), and two water-soluble (WS) P fertilizers – triple superphosphate (TSP) and single superphosphate (SSP). Some of the chemical characteristics of the rock phosphates are presented in Table 12. Phosphorus sufficiency levels were estimated for each of the five soil-test methods by studying the relationship between relative yield (as a percentage of the maximum obtained yield) and available P. Two procedures were used to establish sufficiency levels: (1) the graphic method proposed by Cate and Nelson, and (2) nonlinear regression analysis using models of the form:

$$y = b_1 * [1-b_2 * \exp(-b_3 * x)]$$

where y = relative yield (% of maximum yield); x = available soil P; and b_1, b_2, and b_3 are the estimated regression coefficients. The P-sufficiency level was defined as the amount of available P required to obtain 90% of the maximum yield.

Table 12. Chemical characteristics of Tahoua (TRP) and Parc-W rock phosphate (PWRP) and the corresponding partially acidulated phosphates: PATRP and PAPWRP.

	Acidulation (%)	$Fe_2O_3+Al_2O_3$ (% of rock)	Total P	Soluble P (% of total P)	
				Water	Citrate
TRP	0	12.4	12.1	0	11.8
PATRP	50	-	9.8	28.8	12.8
PWRP	0	2.9	12.4	0	9.0
PAPWRP	50	0	8.8	49.0	9.4

The coefficients of simple determination (R^2) for available P results obtained with the five soil-test procedures were determined for each of the fertilizer types and are reported in Table 13. The R^2 values were very high for the WS fertilizers, suggesting that all soil-testing methods extracted similar forms of soil P and therefore performed equally well in determining plant available P when the soil was fertilized with TSP or SSP. Conversely, the R^2 values for the P were considerably lower and the R^2 values with PARPs were intermediate between those of the WS and the rock phosphates. There is disagreement among scientists about which soil-test procedures to follow when rock phosphate or PARP is used as fertilizer and it is recognized that, for example, the Bray-2 and Mehlich-1 tests use a relatively high concentration of HCl and tend to overestimate available P by dissolving nonreactive rock phosphate or PARP, whereas water or $NaHCO_3$ (used in the Olsen method) may underestimate available P by dissolving less P than the plant absorbs.

Table 13. Coefficient of simple determination (R^2) for different soil testing methods in a soil treated with rock phosphate, partially acidulated rock phosphate (PARP), and water-soluble (WS) fertilizer.

	Bray-1	Bray-2	Mehlich-1	WEP
Rock phosphate				
Bray-2	0.90	-	-	-
Mehlich-1	0.67	0.86	-	-
WEP	0.76	0.74	0.62	-
Olsen	0.43	0.44	0.30	0.52
PARP				
Bray-2	0.89	-	-	-
Mehlich-1	0.83	0.91	-	-
WEP	0.72	0.81	0.73	-
Olsen	0.83	0.91	0.88	0.65
WS fertilizer				
Bray-2	0.96	-	-	-
Mehlich-1	0.97	0.97	-	-
WEP	0.94	0.89	0.94	-
Olsen	0.98	0.91	0.95	0.96

The relationship between relative yields and available P was very poor when rock phosphate was used and treatments including the rock phosphates were eliminated for the determination of P-sufficiency levels. For all five soil-testing methods, the critical levels estimated by the Cate-Nelson method agreed closely with those obtained by fitting nonlinear asymptotic regression functions. When the Bray-P, WEP, and Olsen methods were used, one regression model for each extractant was able to describe the relationship of relative yields and available P for both rock phosphate and WS fertilizers (Table 14.). However, two regressions were needed (one for WS and another for PARP) when the Bray-2, or Mehlich-1 test was used (Table 14). The models for PARP presented smaller slopes than those corresponding to the WS suggesting that the available P values obtained with the Bray-2 and Mehlich-1 methods probably contained some P arising from the dissolution of the rock phosphate portion of PARP that was not available to the crop and thus these methods overestimated available P.

Table 14. Nonlinear regression models of relative yields against available P by five soil-testing procedures and P-sufficiency levels estimated with the regression and with a graphic procedure.

	Bray-1		Bray-2 P		Mehlich-1 P		WEP		Olsen P	
	WS	PARP	WS	PARP	WS	PARP	WS	PARP	WS	PARP
b1	98		95	109	96	99	100		97	
b2	1.56		2.57	0.92	1.41	0.89	1.47		1.57	
b3	0.38		0.46	0.11	0.58	0.19	3.16		0.83	
R^2	0.76		0.92	0.76	0.69	0.80	0.66		0.64	
P-sufficiency level										
Regression	7.9		8.3	15.2	5.5	11.9	0.9		3.8	
Cate-Nelson	7.5		12.0	14.0	7.0	9.0	0.8		3.5	

Considering the regression fit (R^2), standard error of the mean (SE), and the number of observations used for the nonlinear regression analysis, the Bray-1 method appeared to be the most reliable soil-testing procedure to establish P-sufficiency levels in soils fertilized with PARP or WS fertilizers. A Bray-1 value of 7.9 mg ka^{-1} of soil is the sufficiency level needed to achieve 90% of maximum millet yield in a given cropping season.

We developed a quadratic function to describe the relationship between the water-extractable plus citrate-soluble P (WCP) applied and the Bray-1 P value. The amount of WCP required to achieve a given relative yield (y) for a given soil-test value (x) can be calculated as follows:

$$WCP = -2.483 * \frac{\log (98-y)}{142.4} - 943x$$

The amount of P fertilizer to be applied to achieve a given relative yield of millet on the sandy soils of Niger depending of the Bray-1 test are reported in Table 15. For example, if the soil test for Bray-1 is 2 mg P kg^{-1} soil and the farmer wants to achieve 90% of maximum millet yield, he should apply 40 kg P_2O_5 ha^{-1}.

Table 15. Amount of P fertilizer needed to achieve a given relative yield of millet on the sandy soil of Niger.

Bray-1 P test (mg kg^{-1})	Relative yield without P application (%)	P fertilizer needed (kg P_2O_5 ha^{-1}) for relative yield (%) of				
		50	60	70	80	90
2	27	6	11	16	25	40
3	49	-	3	9	18	33
4	65	-	-	2	10	26
5	75	-	-	-	3	19
6	82	-	-	-	-	11
7	87	-	-	-	-	4
8	91	-	-	-	-	-

Recovery of Fertilizer Phosphorus and Sulfur by Pearl Millet

We initiated a trial in 1990 using ^{35}S and ^{32}P labeled fertilizers and different methods of application to study the recovery of fertilizer P and S from double superphosphate, a mixture of single superphosphate (SSP), and triple superphosphate (TSP), containing both P and S. The double superphosphate was compared with triple superphosphate containing no sulfur to determine the response of millet to sulfur.

Four types of fertilizer placement were tested: broadcast (B) broadcast and incorporated (BI), broadcast and ridged (BR), and hill-placed (HP). In 1990, the control plot not receiving P or S fertilizer was split, with half planted on the ridge and half planted on the flat. In 1989 the control plot had been planted only on the flat. Fertilizer was applied at the rate 20 kg P ha^{-1} and 10 kg S ha^{-1}.

In 1989, the broadcast and ridge treatment performed significantly better than the other treatments (B, BI, and HP), but there was no significant difference between the other placement methods. In 1990—a drier year than 1989—there was no significant difference between placement methods. The 1990 control ridge treatment performed significantly better than that planted on the flat for both years. There was no significant response to sulfur application.

The labeled ^{32}P was analyzed at the laboratory of the Institut des Radio-Isotopes (IRI) of the University of Niamey. The P recovery from fertilizer ranged from 10 to 22% in 1989 and from 8 to 14% in 1990. The lower P recovery in 1990 was due to the residual effect of P applied in 1989 (Table 16). For both years, P recovery was significantly lower when fertilizers were hill-placed (HP) than with the other three methods of application.

Table 16. ^{32}P recovery with different methods of fertilizer P application to pearl millet, Sadoré, Niger, 1989 and 1990 rainy seasons.

	Yield (t ha^{-1})				Total uptake (kg ha^{-1})		P derived from fertilizer (%)		Total P derived from fertilizer (kg ha^{-1})		Fertilizer P utilization (%)	
	Head		Stover									
Treatment	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990	1989	1990
Broadcast (BU)	1.04	1.40	2.00	1.97	7.55	7.40	46.00	33.77	3.36	2.45	15.40	12.47
Broadcast and incorporated (EI)	1.13	1.58	2.39	2.13	8.10	7.91	53.42	33.53	4.37	2.70	22.24	13.78
Broadcast and ridged (BR)	1.21	1.55	2.56	2.23	9.12	7.62	46.09	37.74	4.14	2.78	21.09	14.15
Hill-placed (HP)	0.85	1.35	2.00	1.83	4.93	5.55	42.82	28.48	2.02	1.53	10.30	7.83
SE	±0.10	±0.07	±0.29	±0.14	±0.77	±0.44	±3.45	±0.74	±0.45	±0.27	±2.01	±3.6
CV (%)	23	11	33	16	26	16	17.95	20	32	28	29	28

Recovery of Fertilizer Nitrogen by Pearl Millet and Sorghum

Groundnut and cowpea are predominant grain legumes in the WASAT; their beneficial effects–through N_2-fixation–on succeeding crops, especially cereals, are well known.

Since 1988, we have examined the effect of groundnut and cowpea on: (1) the yield of a succeeding cereal crop as compared with continuous cereal cropping in the Sahelian and Sudanian Zones of the WASAT; (2) fertilizer-use efficiency with ^{15}N labeled fertilizer; and (3) the contribution of the soil N to the cereal crop under continuous cereal versus rotation cropping with legumes. We studied field response to N of pearl millet at Sadoré (Fig.11), Tara (Fig.12), and Bengou (Fig.13); and sorghum at Bengou (Fig.14) under the two systems in different agroecological zones of the WASAT (Figs. 11, 12, and 13). The cereal-legume rotation, had a highly significant effect on succeeding cereal grain yields at all locations; for instance, with no N application, total dry-matter yield of sorghum after cowpea increased by 1.28 t ha^{-1} as compared with continuous sorghum cultivation. In general, cowpea seems to be a better legume for rotation than groundnut.

Table 17 shows ^{15}N recovery and contribution of soil N to sorghum under the different cropping systems. Sorghum following groundnut showed 44% fertilizer-use efficiency versus 32% for continuous sorghum, and 89 kg ha^{-1} N uptake versus 38 kg ha^{-1} for continuous sorghum. In 1990, we initiated trials to quantify biological N_2-fixation by groundnut and cowpea, using the ^{15}N isotopic dilution technique.

Table 17. Nitrogen ^{15}N recovery and contribution of soil nitrogen to sorghum under different cropping systems, Bengou, Niger, 1989 rainy seaon.

Cropping System	Total N uptake (kg ha^{-1})	Total ^{15}N recovery (%)	Total N derived from soil (kg ha^{-1})
Sorghum-Sorghum	57	32	38
Cowpea-Sorghum	72	23	54
Groundnut-Sorghum	116	44	89
SE	±7.2	±3.57	±6.25
CV (%)	19.94	23.95	23.00

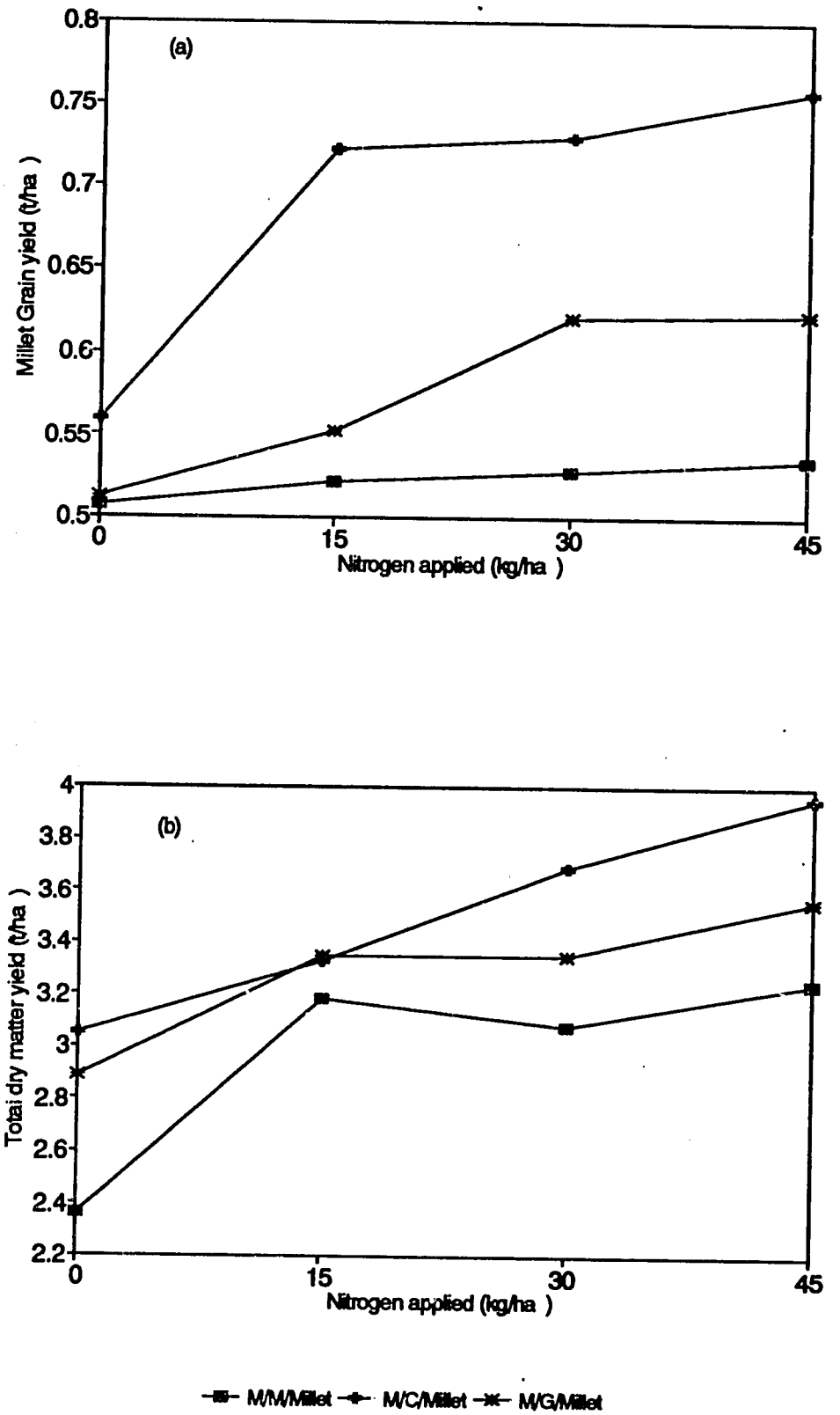

Figure 11. Effect of nitrogen on grain and total dry matter yields of pearl millet under different rotations, Sadoré, Niger, 1990 rainy season.

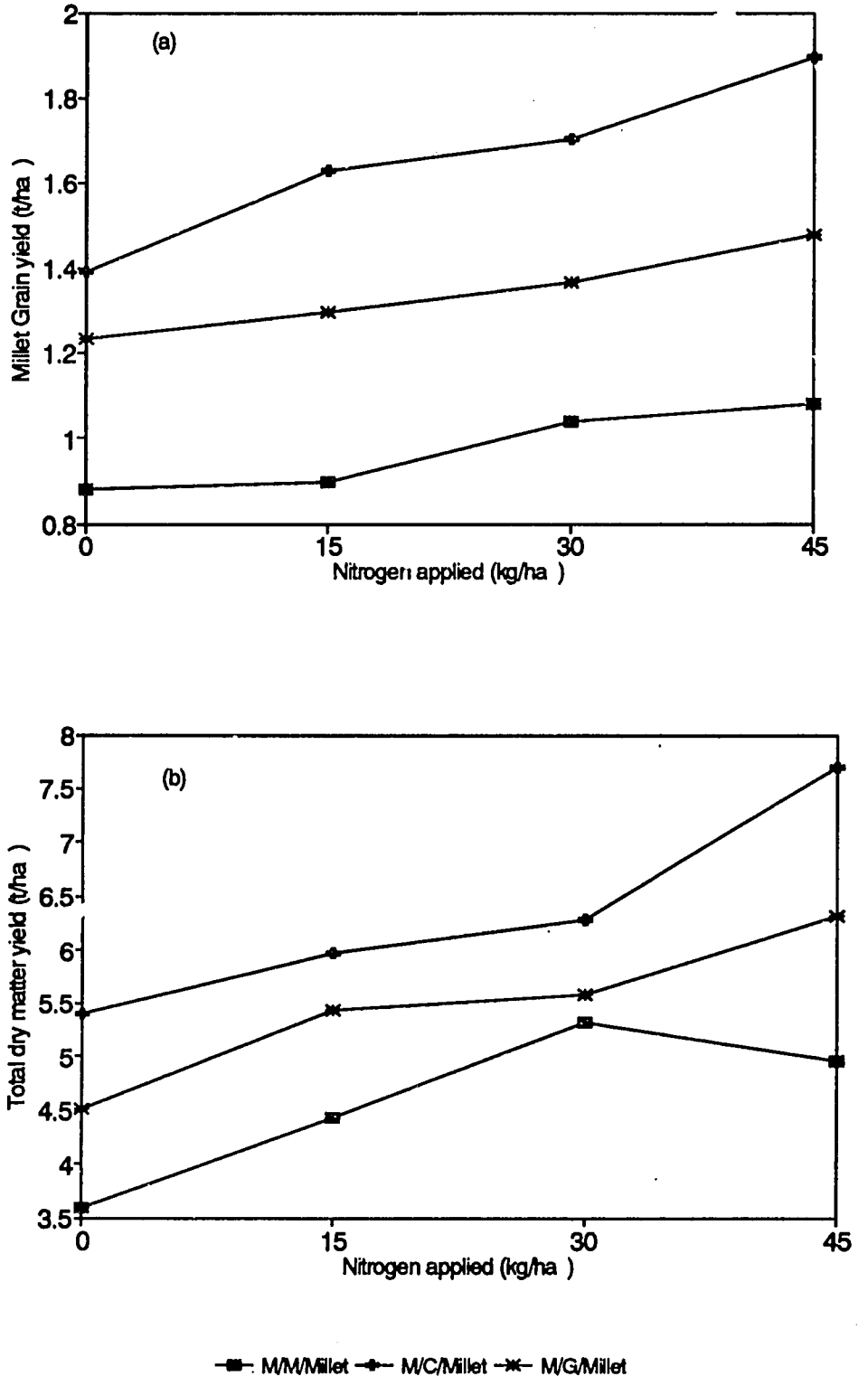

Figure 12. Effect of nitrogen on grain and total dry matter yields of pearl millet under different rotations, Tara, Niger, 1990 rainy season.

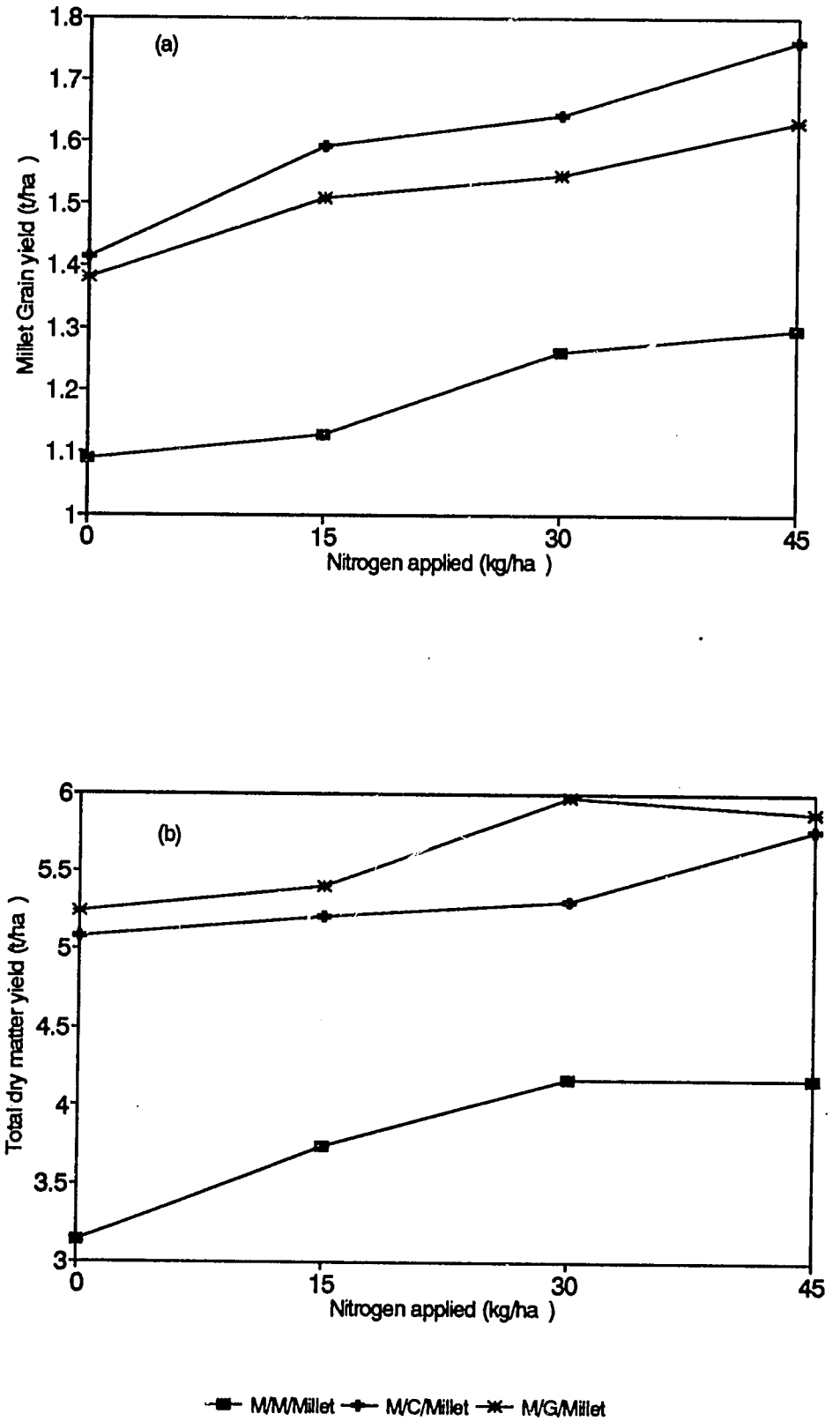

Figure 13. Effect of nitrogen on grain and total dry matter yields of pearl millet under different rotations, Bengou, Niger, 1990 rainy season.

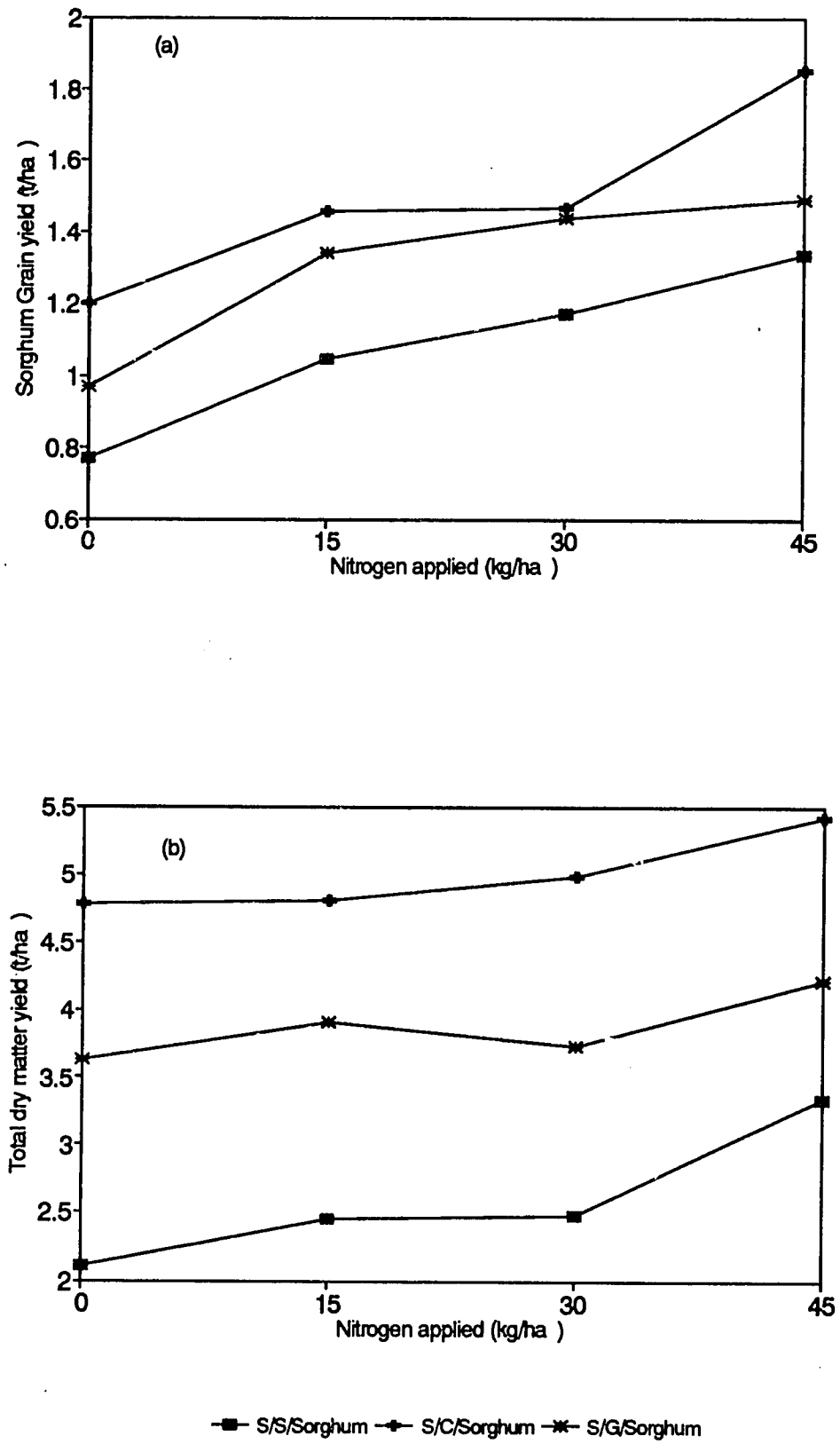

Figure 14. Effect of nitrogen on grain and total dry matter yields of sorghum under different rotations, Bengou, Niger, 1990 rainy season.

Effect of Crop Density and Nitrogen Fertilizer on Pearl Millet

The climate of the Sahel is characterized by large year-to-year variations in rainfall, making it difficult to predict how much moisture will be available for crop production. Consequently, farmers traditionally use very low crop densities for pearl millet, to reduce the risk of yield loss due to drought stress. Although the nationally recommended crop density is 10 000 pockets ha^{-1}, village surveys in Niger have shown that in farmers' fields, densities averaged 5200 pockets ha^{-1}, with wide variation between fields and many sown at much lower rates.

Though numerous trials have shown consistent yield response to P, N response tends to vary with the amount of rainfall. Although rainfall deficits occur for varying periods, those occurring in midseason (stem elongation-anthesis) tended to reduce yield the most (ICRISAT West African Programs Annual Report 1989, p. 68).

To verify the effect of crop density and nitrogen fertilizer on pearl millet, we conducted field experiments during 1983-85 in a split-plot factorial design in randomized complete blocks with crop density in the main plots and N application in the subplots. Yearly rainfall patterns during the experiment years (1983-85) varied greatly. The long-term average rainfall for Sadoré is 560 mm. In 1983, a total 599 mm of rainfall and 290 mm was received in July and August, but in 1985, with a total of 560 mm rainfall, 393 mm was received in July and August. In 1984, the total rainfall was 260 mm, with only 148 mm in July and August.

The regression estimates for the effect of applied N on grain yield as affected by crop densities are reported in Table 18. In 1983, total rainfall approached the long- term average, although a deficit in August limited grain yield, and response to N was more limited at high crop densities (Table 18). In 1984. the dry year, no response to N was found, and grain yields were very poor (Table 18), with high crop densities having a slight negative effect on grain yield. For 1985, both amount and distribution of rainfall were highly favorable for crop growth; yield was high and significant responses were found to both N and high density, with the response to N increasing with increasing density (Table 18).

The results show that the effects of crop density and N- fertilizer rates on grain yield depend on the amount of rainfall over the entire season; however, it should be expected that grain yield will be particularly sensitive to the amount of rainfall received at certain critical growth stages. To identify these growth stages for millet, several multiple-regression models were evaluated; terms were included for main effects and interactions of N fertilizer rates, crop density, and rainfall during different months or groups of months, over the 3 years.

Table 18. Linear regression model parameters for the effect of applied N[1] on grain yield, as affected by crop density, 1983-1985 = $b_o + B_iN$.

Year	Density ('000 pockets ha^{-1})	b_0	b_i	R^2
1983	5	323	11.4	0.99
	10	481	11.4	0.89
	20	1003	8.9	0.86
	40	1468	3.3	0.89
1984	5	506	NS	-
	10	496	NS	-
	20	481	NS	-
	40	336	NS	-
1985	5	494	6.9	0.93
	10	810	19.3	0.98
	20	1009	30.9	0.99

1. Dependent variable = grain yield (kg ha^{-1}); independent variable = N fertilizer (kg N ha^{-1}).

The model that provided the highest R^2 value and smallest standard error was:

$$Y_{ij} = 108 - 8.65\ N_i - 51.13\ D_j - 2.73\ R_k, + 0.071\ N_i\ R_k + 0.304\ D_j \times R_k$$

When Y_{ij} is the estimated grain yield at the ith N rate and jth crop density level, N_i is the ith fertilizer rate (kg N ha^{-1}), D_j is the jth density ('000 pockets ha^{-1}), R_k is the amount of rainfall during the critical growth stage (mm), and $N_i \times R_k$, $D_j \times R_k$ are the interactions of rainfall with N rate and crop density, respectively.

The critical period for rainfall was found to be July and August, which coincides with the culm-elongation and anthesis growth stages of millet. The R^2 for the model is 0.75. Thus, at the nationally recommended crop density of 10 000 pockets ha^{-1}, the model predicts a slightly negative response to N in a drought situation (100 mm midseason rainfall) and only a small response with low rainfall (200 mm). However, when midseason rainfall exceeds the long-term average, a strong response to N is predicted, resulting in a 2.7-fold yield increase for a 60 kg N rate. Similar, more pronounced trends in N response are noted at 20 000 pockets ha^{-1}. Rainfall significantly interacts with crop density, and thus the model predicts a doubling of yield when rainfall is above normal and density is increased from 10 000 to 20 000 pockets ha^{-1}.

Technology Assessment

We routinely conduct on-farm and/or socioeconomic assessment of technologies developed or tested by our scientists and their collaborators. This year, we report on assessments of a low-cost donkey-drawn hoe and soil amendment options for sandy soils.

After successful on-station technical efficiency tests of a low-cost donkey-drawn hoe, we tested the prototype to assess technical efficiency under on-farm conditions. Farmers' reactions to the prototype were elicited. We also used economic efficiency criteria to evaluate soil amendment options that were tested for 6 years at Sadoré.

Prototype Development and On-farm Evaluation of the HATA

Labor bottlenecks occur during weeding in nonmechanized agriculture. Mechanized weeding with animal-drawn implements would enable timely weeding, increasing crop yields while reducing labor demands.

In collaboration with the University of Höhenheim (Germany), we designed an inexpensive labor-saving weeding device. In 1989, a prototype of a donkey-drawn hoe, the Houe à traction asine (HATA) was tested at ISC. Its design–consisting principally of a triangle to which three Iler (the traditional hand tool for weeding) blades are fixed, and a handle to guide the implement–was based on local manufacturing capabilities.

In experiments at ISC, the quality of weeding and labor requirements of the traditional hand-hoe method were compared with those of four animal-drawn weeding implements:

1. ox-drawn trailer-type chain harrow;
2. ox-drawn "arara" tool fitted with three duckfoot shovels;
3. donkey-drawn prototype weeder;
4. donkey-drawn light weeder with three small sweeps.

Results showed significant reductions of about 25% in labor time requirements where animal-drawn weeders were used. Quality of mechanized weeding improved with depth and number of passes over the same row.

On-station improvement of the HATA design involved the attachment of a front skid to permit better depth control. In addition, the skid turned aside crop residues and other materials that remained on the field, allowing the unhampered performance of the cutting blades. Manufacturing costs increase only slightly, because the skid can be manufactured out of scrap material.

Efficiency and labor hours of weeding were determined by comparing the hand tool with the following: a three-tine model with and without a front skid, and a five-tine model without a front skid (Table 19). Results show a significant reduction of labor time with animal-drawn implements.

Table 19. Efficiency (e) of weeding and labor time (t) for different prototypes of the donkey-drawn hoe developed at ISC, Sadoré, Niger, compared with traditional hand hoe.[1]

Implement	3 tines +skid	3 tines -skid	5 tines -skid	Hand (Iler)	SE
e (%)	75	63	73	94	±3.6
t (h ha^{-1})	19.6	20.3	14.5	33.2	±0.2

1. Pearl millet field (ridged and flat) with *Jacquemontia tamnifolia* (L.) Grieb., *Hibiscus sabdariffa* L., and *Cenchrus biflorus* Roxb. as dominant weed species, average weed population 240 kg ha^{-1}.

Draft force requirements of the three-tine models were F = 275 N (± 7); while draft forces for the five-tine model reached F = 350 N. Working depth for all models was 5-10 cm. The model with a skid was easier to handle than the one without a skid.

On-farm trials were conducted in cooperation with the "Project agro-sylvo-pastoral Nord Niamey" (PASP) and the "Project d'animation rurale intégrée de la Vallée de Sirba" (PARIS).

The trials focused on comparisons of labor time for mechanized and manual weeding and farmers perceptions about the usefulness of the HATA.

Eleven prototypes were distributed in villages in the arrondissements of Say, Tera, Tillabéry, Ouallam, and Filingué, and 66 models were manufactured by local blacksmiths. The capability of village blacksmiths to manufacture the implement was promising. Although not all blacksmiths were able to do the work properly, there were at least craftsmen in neighboring villages with a good manufacturing capability. All workshops were equipped with simple tools, none had welding equipment. Raw materials were mainly bought in Niamey.

Time spent on weeding operations using the HATA or Iler was monitored on farmers' fields. Although each implement required the services of an adult and a child, there were large differences in the actual times spent on weeding: an average of 71 h ha^{-1} with the Iler, versus only 37 h ha^{-1} with the HATA. The HATA, therefore, permits, on the average, about 50% reduction in labor time spent on manual weeding.

Participating farmers were questioned about implement design and animal harnessing aspects. General response to the efficiency of mechanized weeding was positive. Farmers did not seem to consider the problem of in-row weeding with an animal-drawn implement a major negative aspect. Indeed, the traditional system requires a second passage during thinning operations, and this was combined with in-row weeding by the prototype.

Farmers also responded positively to the reduced labor time required for weeding with the HATA. No farmer mentioned the fitting of the harness as a major problem. Most of the sample farmers had donkeys for draft work. Some farmers provided supplementary food for their donkeys.

On-farm evaluation will be extended next season, with emphasis on design improvements, and management and economic aspects.

Stochastic Dominance Evaluation of Soil Amendment Options

The poor physical and chemical characteristics of the predominantly sandy soils in the Sahel represent major constraints to cereal and legume production. Long-term trials were started in 1984 at Sadoré, to test a number of soil amendment options for these sandy Sahelian soils. The soil amendments tested comprised annual applications of P in the form of rock phosphate, 50% partially acidulated rock phosphate (PARP), and single superphosphate (SSP); periodic applications of farmyard manure (FYM), or combinations of annual P plus periodic manure applications. The ten treatments included in the trials are presented in Table 20. All the treatments received annual applications of 30 kg N ha^{-1} and 30 kg K ha^{-1}. Chemical analysis of samples showed that the FYM used contained about 32.1% organic matter, 0.405% total P, 1.21% total N, and had a pH (KCL) of 7.7.

Excellent rainfall may explain the higher yields obtained in 1985 (Table 21). Generally, best yields were obtained where 20 t ha^{-1} of FYM were applied every 3 years, either sole or in combination with annual application of 17.5 kg P ha^{-1} from SSP. As expected, grain yields were lowest for the control, where no manure or P was applied. Much higher yields were obtained with 5 t ha^{-1} or 20 t ha^{-1} FYM combined with P, than with either FYM or P applied alone. More

Table 20. Soil amendment options tested for sandy Sahelian soil in long-term trials at ISC, 1984-90.[1]

Treatment	Treatment details
Control	No FYM or P applied
Man5	5 t ha^{-1} FYM applied in 1984 and 1987
Man20	20 t ha^{-1} FYM applied in 1984 and 1987
SSP8.7	8.7 kg ha^{-1} P from SSP applied annually
SSP17.5	17.5 kg ha^{-1} P from SSP applied annually
Rock phosphate 39.3	39.3 kg ha^{-1} P from rock phosphate applied annually
SSP8.7 + Man5	8.7 kg ha^{-1} P from SSP applied annually plus 5 t ha^{-1} FYM applied in 1984 and 1987
SSP17.5 + Man20	17.5 kg ha^{-1} P from SSP applied annually plus 20 t ha^{-1} FYM applied in 1984 and 1987
PARP8.7 + Man5	8.7 kg ha^{-1} P from PARP50 applied annually plus 5 t ha^{-1} FYM applied in 1984 and 1987
Rock phosphate 39.3 + Man5	39.3 kg ha^{-1} P from rock phosphate applied annually plus 5 t ha^{-1} FYM applied in 1984 and 1987

1. Randomized complete block design with 8 replications; plot size 64 m^2.

Table 21. Pearl millet grain yields obtained with different soil amendments and postharvest prices of millet grain.

	Mean grain yield (kg ha^{-1})				
Soil amendment[1]	1985	1986	1987	1988	1989
Control	416	502	580	362	209
Man5	1122	593	772	723	356
Man20	1735	1544	1265	1457	708
SSP8.7	1103	882	594	734	408
SSP17.5	1335	1379	820	851	575
Rock phosphate 39.3	1101	842	675	485	284
SSP8.7 + Man5	1589	1379	990	1093	530
SSP17.5 + Man20	1464	1873	1226	1508	865
PARP8.7 + Man5	1293	1027	789	926	423
Rock phosphate 39.3 + Man5	1376	1303	999	952	497
Treatment mean	1253	1132	871	909	486
SE	±78	±81	±58	±90	±42
Millet price (FCFA kg^{-1})	75	70	63	51	45

1. See Table 20 for details of soil amendments. About 275 FCFA = U.S. $1.

importantly, incremental yields over the control, for a combination of P from rock phosphate and FYM were larger than the sum of incremental yields for the individual components in every year except 1985. This suggests possible synergy between P and FYM at some levels of application. However, where 20 t ha^{-1} of FYM was applied, additional

application of 17.5 kg P ha^{-1} in the form of SSP did not give large yield increases, except in 1986. The implication is that where farmers can apply 20 t ha^{-1} FYM every 3 years, supplementary application of P may be unnecessary.

Due to temporal differences in costs and market prices, choices based on comparative yields may not be efficient. Six years of grain yield data, postharvest market prices for pearl millet, and cost information were used to evaluate the relative effectiveness and economic value of soil amendment options tested in the trials. Net returns were calculated by deducting cost of inorganic fertilizers and FYM from the value of yields.

Stochastic dominance was used as the conceptual framework for making efficient choices within an expected utility framework. The underlying behavioral assumption in searching for stochastic efficiency is that dominated distributions will not be preferred by expected utility maximizing risk-averse farmers. Net return distributions for a treatment A are said to be dominated if, at all or most similar probabilities of occurrence, they are lower than net return distributions of another treatment. All dominated options were then deleted, since they are inefficient, and the remaining efficient options were compared by applying the concept of partial first-degree stochastic dominance.

An important component of stochastic dominance analysis is the source of the probabilistic data. The most important index of growing conditions in the Sahel is the rainfall amount and its temporal distribution. Moreover, rainfall affects the effectiveness of soil amendments. Rainfall data for Niamey over 80 years were used to compute objective probabilities for rainfall that occurred in each of the trial years. These formed the basis for assigning subjective probabilities to corresponding years.

Table 22 presents distributions of net returns and associated probabilities used for pairwise comparisons of soil amendment alternatives, within the stochastic dominance framework. Costs closely followed the three levels of FYM application: 0, 5, and 20 t ha^{-1} of FYM. It was therefore instructive to compare soil amendment options that have similar costs.

Where no FYM was applied, the control, annual applications of 17.5 kg P ha^{-1}, or 8.7 kg P ha^{-1} from SSP are the efficient options (Table 23). However, the lack of dominance between them was due to the relative losses in the drought year of 1984.

When returns for 1984 are ignored, under partial first-degree stochastic dominance analysis, annual application of 17.5 kg P ha^{-1} dominates both the control and annual application of 8.7 kg P ha^{-1} (Table 24).

Therefore, if a farmer has no access to FYM, the utility-maximizing strategy will be to apply 17.5 kg P ha^{-1} in the form of SSP. From similar pairwise comparisons of treatments that included applications of 5 t ha^{-1} FYM every 3 years, the utility-maximizing strategy will be to apply the manure in combination with an annual application of 8.7 kg ha^{-1} P from SSP.

Table 22. Empirical distribution of annual net returns, in thousands of FCFA, and subjective probabilities.[1]

Treatment	Year					
	1984	1985	1986	1987	1988	1989
Control	-8	23	27	28	10	1
Man5	-28	76	33	20	28	8
Man20	-88	122	100	-9	66	23
SSPP8.7	-13	69	48	23	23	4
SSP17.5	-18	81	77	32	24	6
Rock phosphate 39.3	-15	67	43	27	9	-3
SSP8.7 + Man5	-34	105	83	28	42	10
SSP17.5 + Man20	-100	90	112	-22	57	19
PARP8.7 + Man5	-32	84	59	17	34	6
Rock phosphate 39.3 + Man5	-35	87	75	27	33	6
Subjective probability	0.005	0.24	0.12	0.395	0.085	0.155

1. The subjective probabilities were formed on the basis of normalization of rainfall probabilities to satisfy the statistical condition that cumulative probability over an exhaustive set should be equal to 1. About 275 FCFA = U.S. $1.

Table 23. Dominance comparisons of empirical distributions of net returns and associated subjective probabilities.[1]

Treatment[2]	Treatment no. 1	2	3	4	5	6	7	8	9
Control (1)									
Rock phosphate 39.3 (2)	-								
SSP8.7 (3)	-	S							
SSP17.5 (4)	-	-	-						
SSP8.7 + Man5 (5)	-	-	-	-					
Rock phosphate 39.3 + Man5 (6)	-	-	-	<S	<F				
PARP8.7 + Man5 (7)	-	-	-	<S	-	-			
Man5 (8)	-	-	<S	<S	-	-	-		
SSP17.5 + Man20 (9)	-	-	-	<S	<S	<S	<S	-	
Man20 (10)	-	-	-	-	<S	-	-	-	F>

1. "S>" denotes second-degree stochastic dominance of row treatments over corresponding column treatments; "<S" denotes second-degree stochastic dominance of column treatments over corresponding row treatments; "<F" denotes first-degree stochastic dominance of column treatments over corresponding row treatments; "F>" denotes first-degree stochastic dominance of row treatments over corresponding column treatments; "-" denotes no dominance.
2. See Table 20 for treatment details.

Table 24. Partial first-degree stochastic dominance comparisons of net returns of efficient treatments.

Treatment	Treatment (a)	(b)	(c)
Control (a)			
SSP8.7 (b)	-[1]		
SSP17.5 (c)	PF>[2]	PF>	
SSP8.7+Man5 (d)	PF>	PF>	-

1. "-" denotes no partial first-degree stochastic dominance;
2. "PF>" denotes partial first-degree stochastic dominance of column treatment by row treatment.

Comparison of the two treatments where 20 t FYM ha^{-1} were applied showed that additional annual application of 17.5 kg P ha^{-1} in the form of SSP would be inefficient. However, the FYM applied at 20 t ha^{-1} every 3 years is dominated by the option of combining 5 t ha^{-1} FYM and 8.7 kg ha^{-1} P from SSP. In practice, an individual farmer's choice between these two treatments will depend on the availability of FYM and on the added labor and transportation requirements for spreading the FYM where no paddocking was done. Therefore, it is not possible to prescribe an optimal strategy for all. However, in view of the need to increase the organic matter content of sandy soils in the Sahel, periodic application of some FYM may be necessary. For this reason, and considering the meager resources of Sahelian farmers, the most appropriate soil amendment option would be annual applications of 30 kg N ha^{-1}, 30 kg K ha^{-1} and, 8.7 kg P ha^{-1} in the form of SSP, and 5 t FYM ha^{-1} every 3 years.

West African Sorghum Improvement Program/Mali

Introduction

The West African Sorghum Improvement Program (WASIP) in Mali aims at improving sorghum production in the Sudano-Guinean and Guinean Zones (800-1200 mm annual rainfall) in the region where production potentials are high. This program is a collaborative effort between CIRAD/IRAT and ICRISAT, with both providing scientific personnel and funding. The multidisciplinary team includes an agrophysiologist (team leader, IRAT group), an entomologist, a sorghum breeder, and a *Striga* specialist from CIRAD/IRAT and a sorghum breeder, a pathologist, an economist and team leader from ICRISAT. The pathologist is also the Network Coordinator, West and Central Africa Sorghum Research Network (WCASRN), which is funded by SAFGRAD/USAID.

By the end of 1990, the WASIP building complex was ready for use and most laboratory equipment had arrived. The Entomology program initiated stem borer rearing in the new laboratory.

Biotic Stresses

Diseases

Initial Leaf Disease Nursery

The objective of the initial foliar-disease nursery was to evaluate several sorghum genotypes for their reaction to leaf anthracnose (*Colletotrichum graminicola*) and grey leaf spot (*Cercospora sorghi*), the two most prevalent leaf diseases on both local and introduced sorghums in the Northern Guinean Zone (1000-1200 mm rainfall). We plan to identify sources of resistance to both diseases for use in breeding programs in West Africa. We therefore evaluated local guinea sorghums, obtaining seed from our collaborators in the national programs of Benin, Burkina Faso, Cote d'Ivoire, Ghana, Mali, and Togo.

We grew the nursery at Longorola and Samanko in Mali in 1989 (41 entries) and 1990 (42 entries); 70-80% of the entries in both years were local genotypes. Although both locations are in the Northern Guinean Zone, grey leaf spot rarely attains epidemic proportions at Samanko. Total rainfall between June and October was 988 mm in 1989 and 825 mm in 1990 at Longorola; 847 mm in 1989 and 828 mm in 1990 at Samanko. Because of poor stand, only results from 39 entries were analyzed at Longorola in 1989. Disease severity from natural inoculum was assessed at 30 days after 50% flowering for each genotype, scored on a scale of 1-6, where 1 = no symptoms; 2 = up to 5%, 3 = 6-25%, 4 = 26-50%, 5 = 51-75%, and 6 = more than 75% leaf area infected.

We report only genotypes with mean disease scores of 2 or less (resistant) or up to 3 (moderately resistant) in both years at both locations. Our results indicate that 11 local genotypes met these criteria for leaf anthracnose (Table 1) and four of the eight test germplasm lines met these criteria for grey leaf spot (Table 2). Several local genotypes were resistant to leaf anthracnose, and one germplasm line, IS 9738, was either resistant or moderately resistant to both diseases.

This initial nursery will be followed by further testing during one more season with higher inoculum levels, using either the composite spreader-row technique or artificial inoculation.

Insect Pests

Head Bugs

Screening for resistance to head bugs. To confirm levels and stability of head bug resistance across years and locations, we evaluated again the same 12 sorghum cultivars as last year, sown on two dates at the same three locations (Samanko and Cinzana in Mali, and Farako-Bâ in Burkina Faso) (ICRISAT West African Programs Annual Report 1989, p. 93). The same observations were taken on head bug infestation and damage, under both natural and artificial

Table 1. Local sorghum genotypes resistant or moderately resistant to leaf anthracnose (*Colletotrichum graminicola*) from natural inoculum in an initial leaf disease nursery at Longorola and Samanko, Mali, rainy seasons 1989 and 1990.

	Disease severity[1]						
	Longorola		Samanko				
Genotype	1989	1990	1989	1990	Maturity cycle	Height	Grain color
Boper R3	1.0	1.0	1.5	1.5	L	T	White
Boper R4	1.0	1.0	1.0	2.0	L	T	Light cream
Boper R5	1.0	2.0	2.0	2.0	L	T	White
Kampt GLM	1.0	1.0	1.5	2.0	L	T	White
Blanc-Karimana	1.0	1.0	2.5	3.0	L	T	White
NSV-1	1.0	1.0	2.0	1.5	L	T	White
Mankangara	1.0	1.0	1.0	1.5	L	T	White
Local 29	1.0	1.0	1.0	2.5	L	T	White
NSV 68	1.0	1.5	2.0	1.5	M	T	White/red blotch
NSV 74	1.0	1.0	1.0	1.5	M	T	White/red blotch
NSV 83	1.0	1.0	2.5	2.0	M	T	Brown
Susceptible control							
IS 18696	5.0	6.0	6.0	6.0	M	S	Red
Trial mean[2]	1.5	1.6	1.7	2.2			

1. Disease severity based on plot scores on a 1-6 scale, where 1 = no symptoms and 6 = >75% leaf area infected. Single 4-m-row plots with 2 replications. M = medium-duration (65-85 days), L = long-duration (>85 days to 50% flowering); S = short (< 2 m); T = tall (>3 m).
2. Number of entries: 1989, 39 at Longorola and 41 at Samanko; 1990, 42 at both sites.

Table 2. Sorghum genotypes with low disease severity to grey leaf spot (*Cercospora sorghi*) from natural inoculum in an initial leaf disease nursery at Longorola and Samanko, Mali, rainy seasons 1989 and 1990.

	Disease severity[1]						
	Longorola		Samanko				
Genotype	1989	1990	1989	1990	Maturity cycle	Height	Grain color
IS 2579	1.0	3.0	1.0	1.0	I	S	White
IS 8185	1.0	1.0	1.0	1.0	L	T	Brown
IS 8607	1.0	1.5	1.0	1.0	L	T	Brown
IS 9738	1.0	2.0	1.0	1.0	M	S	White
Eno	1.0	1.0	1.0	1.0	M	S	White
Susceptible control							
IS 6109	4.0	5.0	2.5	1.5	L	M	White/red blotch
Trial mean[2]	2.7	4.5	1.8	1.8			

1. Disease severity based on plot scores on a 1-6 scale, where 1 = no symptoms and 6 = >75% leaf area infected. Single 4-m-row plots with 2 replications. M = medium-duration (65-85 days), L = long-duration (>85 days to 50% flowering); S = short(< 2 m); T = tall (>3 m).
2. Number of entries: 1989, 39 at Longorola and 41 at Samanko; 1990, 42 at both sites.

infestation. In addition, 1000-grain mass, percent "floaters" in a sodium nitrate solution of specific density of 1.205, vitrosity, and percent germination were measured for protected and infested panicles for all 12 entries. Head bug population buildup and damage scores are shown in Tables 3, 4, and 5.

This year again, head bug infestation was maximum at Samanko with both dates of sowing (DOS). We recorded less than 25 head bugs per five panicles on cv Malisor 84-7 and CSM 388 (mean of all three locations and both DOS) versus more than 110 on Gadiaba, ICSV 1143 BF, and ICSV 1166 BF. Under natural infestation, Malisor 84-7 had a mean damage score of 2 and CSM 388 had 1.5, compared with 4 for S 34 and Framida. However, such differences narrowed down under cage conditions: at Samanko, we recorded a mean population buildup of 34 head bugs per panicle on Malisor 84-7 and 50 on CSM 388, compared with 89 on Gadiaba and 67 on Framida. Damage rating under artificial infestation was 3 in Malisor 84-7 and 2.2 in CSM 388, compared with 7.1 in the susceptible control, S 34.

Grain quality, measured under artificial infestation, showed a 40% reduction only in vitrosity in Malisor 84-7 and no sigificant change in CSM 388. But S 34 showed markedly reduced quality: 44% lower 1000-grain mass and 49% higher floaters; 80% lower vitrosity; and 35% lower germination.

The best-yielding entries at Samanko and Cinzana were Framida and ICSV 1143 BF (3.5 t ha^{-1}, SE ±0.19 and ±0.25, respectively; plot size 7.5 m^2).

Breeding for resistance. Forty-three F_7 and F_8 progenies derived from crosses between high-yielding sorghum varieties (notably ICSV 1002) and varieties less susceptible to head bugs (notably Malisor 84-7) were evaluated along with four controls under natural head bug infestation (two DOS at Samanko and one at Farako-Bâ).

With the first DOS at Samanko, infestation was medium (general mean of 85.3 head bugs per five panicles). Thirteen entries had a better visual score (on a 1-9 scale) than Malisor 84-7 (3.0), the best of them being 87 W 810

Table 3. Number of head bugs on 12 sorghum cultivars in the advanced head bug screening trial at Samanko (SA), Cinzana (CZ), and Farako-Bâ (FB) under natural infestation, rainy season 1990.[1]

	Head bug no. per 5 panicles[2]											
Cultivar	SA1		SA2		CZ1		CZ2		FB1[3]		FB2	
ICSV 16-5 BF	174	(13.1)	187	(13.4)	103	(10.2)	28	(4.9)	0	(0.3)	17	(3.8)
Framida	145	(11.7)	98	(9.2)	50	(7.1)	50	(6.9)	1	(0.8)	53	(7.0)
ICSV 1143 BF	324	(17.9)	163	(16.7)	142	(11.4)	71	(7.9)	1	(0.7)	9	(2.8)
ICSV 1063 BF	361	(18.6)	178	(12.3)	67	(8.0)	67	(6.8)	1	(0.7)	55	(7.2)
ICSV 2 IN	26	(5.1)	283	(16.7)	117	(10.5)	58	(6.6)	0	(0.3)	79	(8.6)
ICSV 1166 BF	266	(14.8)	150	(12.3)	248	(15.0)	14	(3.0)	7	(2.1)	16	(3.9)
ICSV 1122 BF	67	(8.0)	143	(11.9)	167	(12.4)	19	(4.2)	0	(0.3)	41	(6.2)
Gadiaba	155	(12.4)	385	(19.4)	89	(9.0)	23	(4.8)	1	(0.6)	14	(3.7)
CSM 63	9	(2.9)	43	(6.1)	35	(5.9)	44	(6.6)	2	(1.3)	3	(1.8)
Control												
S 34 (susceptible)	95	(9.7)	77	(8.7)	95	(9.3)	32	(5.6)	3	(1.8)	71	(8.2)
Malisor 84-7 (resistant)	26	(4.9)	47	(6.5)	24	(4.9)	4	(1.3)	0	(0.3)	19	(4.2)
CSM 388 (local)	62	(7.4)	55	(7.1)	0	(0.3)	3	(1.3)	4	(2.1)	9	(2.5)
SE		(±1.43)		(±1.81)		(±1.54)		(±1.52)		-		(±1.08)
Mean		(10.5)		(11.3)		(8.7)		(5.0)		(0.9)		(5.0)
CV (%)		(23.5)		(27.7)		(30.7)		(52.5)		-		(37.6)

1. Randomized complete block design with 3 replications for each location and date of sowing; 1 = first and 2 = second date of sowing.
2. Figures in parentheses are square-root values.
3. Values too low for a formal analysis.

Table 4. Head bug damage under natural infestation on 12 sorghum cultivars of the advanced head bug screening trial at Samanko (SA), Cinzana (CZ), and Farako-Bâ (FB).[1]

	Damage rating[2]					
Cultivar	SA1	SA2	CZ1	CZ2	FB1	FB2
ICSV 16-5 BF	2.8	2.8	3.0	2.0	2.3	2.7
Framida	3.8	4.0	3.7	4.0	4.3	4.0
ICSV 1143 BF	3.2	3.7	3.0	3.0	2.3	3.3
ICSV 1063 BF	3.3	3.5	3.0	3.3	3.7	4.0
ICSV 2 IN	3.7	3.2	3.0	3.0	3.0	4.3
ICSV 1166 BF	3.0	3.2	2.0	3.3	1.3	3.3
ICSV 1122 BF	3.5	3.7	2.0	4.0	3.7	5.0
Gadiaba	3.2	2.8	3.0	2.7	3.0	4.0
CSM 63	2.5	2.5	3.0	2.3	2.0	2.3
Control						
S 34 (susceptible)	3.8	6.3	2.7	4.7	2.3	4.0
Malisor 84-7 (resistant)	2.7	2.0	1.3	1.7	1.7	2.7
CSM 388 (local)	1.8	1.8	1.0	1.0	1.7	1.7
SE	±0.23	±0.35	±0.28	±0.35	±0.38	±0.46
Mean	3.1	3.3	2.6	2.9	2.6	3.4

1. Randomized complete block design with 3 replications for each location and date of sowing; 1 = first and 2 = second date of sowing.
2. Damage scored on a 1-9 scale where 1 = grains with a few feeding punctures and 9 = grains showing more than 75% shriveling.

Table 5. Head bug number and damage under artificial infestation on 12 sorghum cultivars in the advanced head bug screening trial at Samanko, Mali, rainy season 1990.[1]

	Head bug no. per panicle[2]		Damage rating[3]	
Cultivar	DOS1	DOS2	DOS1	DOS2
ICSV 16-5 BF	49 (6.0)	49 (6.9)	3.0	3.7
Framida	115 (10.6)	88 (9.3)	5.8	4.5
ICSV 1143 BF	101 (10.0)	87 (9.2)	4.0	4.0
ICSV 1063 BF	83 (9.1)	81 (9.0)	3.2	4.8
ICSV 2 IN	645 (6.5)	64 (7.8)	3.2	5.2
ICSV 1166 BF	62 (7.8)	73 (8.5)	4.0	4.2
ICSV 1122 BF	21 (4.6)	26 (5.1)	5.5	5.7
Gadiaba	145 (12.0)	96 (9.7)	4.0	4.0
CSM 63	113 (10.6)	52 (7.1)	3.0	3.2
Controls				
S 34 (susceptible)	60 (7.7)	52 (7.2)	7.7	6.5
Malisor 84-7 (resistant)	45 (6.7)	31 (5.5)	3.0	3.0
CSM 388 (local)	98 (9.8)	[illegible] (6.3)	2.3	2.0
SE	(±0.87)	(±0.80)	±0.37	±0.48
Mean	(8.5)	(7.6)	4.1	4.2
CV (%)	(17.7)	(18.0)	-	-

1. Randomized complete block design with 3 replications for each date of sowing (DOS); 1 = first date and 2 = second date of sowing.
2. Figures in parentheses are square-root values.
3. Damage scored on a 1-9 scale where 1 = grain with a few feeding punctures and 9 = grain showing >75% shriveling.

(2.0) and CSM 388, the local control (1.5). With the second DOS, infestation at Samanko was higher (general mean of 105.2 head bugs per five panicles). No entry performed better than the controls Malisor 84-7 (visual score 2.7) and CSM 388 (2.0).

At Farako-Bâ, infestation was lower (general mean 61.5 head bugs per 5 panicles) and the entries showed no significant differences in damage scores. The best-yielding entry was CSM 388 (2 t ha^{-1}); S 34 yielded 1.33 and Malisor 84-7 yielded 1.29 t ha^{-1} (SE ±0.29, plot size 7.5 m^2).

Selections were made from the most promising entries, and these will be evaluated next year under artificial infestation.

Storage Pests

We made a survey of losses caused by insect pests in stored sorghum in the four Malian villages selected for the village-level studies of the Agroeconomics subprogram.

Twenty-seven storage structures were sampled monthly between April and September 1990. Weight loss due to insects was assessed in the laboratory, with a second estimation made after all hidden forms of the pests had emerged from the grain. Monthly loss figures were then related to the pattern of consumption and cumulative weight loss figures over the storage period obtained.

The major pest encountered in all four villages was the grain borer, *Rhyzopertha dominica*, with a maximum population level of 6000 insects. Others were: *Sitophilus oryzae* and *S. zeamais; Tribolium castaneum* and *T. confusum; Trogoderma* sp; *Oryzaephilus mercator; Carpophilus* sp; *Cocyra cephalonica*; and *Sitotroga cerealella*.

Except in sorghum grain stored in bags, losses were very low–generally less than 1% weight loss over the storage period– especially in sorghum stored as bundles of heads. However, given the small number of stores studied, we found no significant differences among sorghum varieties, types of storage structure, or methods of storage.

Next year we will finalize a technique to screen sorghum material for resistance to *R. dominica*, to avoid the release of supersusceptible improved varieties at the village level.

Plant Improvement

In 1990, we continued our breeding program to improve guineense sorghums for productivity and caudatum types for resistance to grain mold.

Pedigree Breeding

We selected agronomically superior plants of different maturity durations from several types of crosses, as follows:

- Of 115 F_3 lines from 16 caudatum × caudatum crosses evaluated, 84 plants;
- Of 116 F_3 lines from 16 guineense × guineense crosses evaluated, 96 plants;
- Of 16 F_2 populations (shallu × guineense) evaluated, 54 plants from 12 crosses (segregants were generally tall);
- Of 6 F_2 populations of crosses between male-sterile panicles of caudatum composite and guineense varieties evaluated, 18 plants (segregants were in general mediocre).

We also made appropriate crosses of selected parents in our population breeding program to develop caudatum and guineense composites.

Evaluation of Caudatum and Guineense Germplasm Collection

Field Evaluation

Preliminary evaluation of a total of 103 caudatum cultivars and 113 guineense cultivars was carried out at Samanko for yield, agronomic characters, and disease resistance to choose promising parents for the breeding program. Those

selected for grain mold resistance (all red grain) were: IS 9484 and IS 2150 from our world collection and R 27 and R 377 from Togo.

The guineense types selected for productivity were: IS 14375, IS 14378, IS 14388, IS 26051, and IS 26057 from the world collection; CSM 323, CSM 388, CSM 398, and CSM 660 from Mali; and 87-41, 87-85, 87-86, 87-87, 87-89, 89-2, and 53-1 from Senegal.

Test of Grain Quality after Harvest

Grain samples of 162 caudatum and guineense cultivars taken at harvest were observed for germination capability, grain mold incidence, and grain vitrosity, following routine procedure. The results (Table 6) showed that the guineense types had better germination, less grain mold, and more corneous endosperm than the caudatum types. Within the caudatum group, germination capability increased and grain mold incidence decreased from early-flowering to later-flowering types; however, grain vitrosity remained unchanged.

Table 6. Comparison of caudatum and guineense sorghums for grain quality.

Race	Time to flowering (days)	No. of varieties	Germination (%)[1]	Grain mold rating[2]	Grain vitrosity[3]
Caudatum	<60	8	33.4(±17.6)[4]	3.1(±0.93)	4.4(±0.74)
	60-69	20	51.3(±20.2)	2.9(±0.97)	4.5(±0.65)
	70-79	35	56.7(±14.9)	2.6(±0.72)	4.4(±0. 64)
	80	19	77.8(±15.2)	2.1(±0.85)	4.2(±0.77)
Guineense	<60	10	81.3(±12.4)	2.8(±0.75)	1.7(±0.80)
	60-69	8	73.4(±16.4)	2.5(±0.71)	2.1(±0.80)
	70-79	11	81.1(±12.4)	1.8(±0.41)	1.9(±0.45)
	80	51	88.2 (±8.8)	1.3(±0.50)	1.6(±0.45)

1. Each lot 200 grains at 30°C temperature for 4 days.
2. Threshed grain mold rated on a 1-5 scale where 1 = no mold and 5 = >50% grain severely molded.
3. Rated on a 1-5 scale where 1 = entirely corneous endosperm and 5 = entirely floury endosperm.
4. Figures in parentheses are standard deviations.

Breeding Medium-duration Varieties

Germplasm Enhancement

To improve our breeding lines further for head bug and grain mold resistance and for grain quality (hard grain), we grew out 75 F_2 segregating populations and the progenies of 56 F_4s and 121 F_5s, selecting several individual plants from these. We crossed Nagawhite with ICSV 1063 BF and ICSV 1079 BF to remove the subcoat in its grain. In the F_2 generation, we selected a few plants with grain resembling that of Nagawhite, but without the subcoat. We also initiated a program of improvement of local varieties from Ghana (NSV 1), Benin (Blanc de Karimama), and Mauritania (Nebana Bedha and Lekweri). Several F_2 plants were selected from crosses involving these local varieties and improved ones.

Yield Trials

We conducted a total of six yield trials of our breeding lines. Four of the breeding lines in Trial 1 produced higher grain yields than all the control varieties; in Trial 2, three lines gave higher yields than the best control, Malisor 84-1 (Table 7). In both trials, the local control, CSM 388, yielded less than the selected breeding lines.

Table 7. Performance of selected sorghum breeding lines in two trials at Samanko and Cinzana, Mali, rainy season 1990.[1]

Line	Grain yield (t ha^{-1})			Time to flowering (days)			Plant height (m)		
	Samanko	Cinzana	Mean	Samanko	Cinzana	Mean	Samanko	Cinzana	Mean
Trial 1									
89W774	3.97	3.45	3.71	77	66	72	1.85	2.11	1.98
89W771	3.12	4.08	3.63	82	69	76	1.82	2.23	2.03
89W785	2.91	3.88	3.40	80	65	73	1.85	2.07	1.96
89W772	2.89	3.80	3.35	82	68	75	1.92	2.30	2.11
Control									
ICSV 1063 BF	2.93	3.65	3.29	81	67	74	1.89	2.04	1.97
Malisor 84-1	1.73	4.04	2.89	75	60	68	1.61	2.32	1.97
Malisor 84-7	1.71	2.75	2.23	87	64	76	1.32	1.31	1.32
CSM 388	2.56	2.47	2.51	86	71	79	4.02	3.78	3.90
SE	±0.358	±0.319		±2	±1		±6	±9	
Mean (20 entries)	2.33	3.35		82	67		2.05	2.22	
CV (%)	27	16		5	4		5	7	
Trial 2									
89W802	3.30	3.72	3.51	81	67	74	1.77	1.90	1.84
89W791	3.17	3.79	3.48	74	66	70	1.65	1.90	1.78
89W807	2.81	3.30	3.06	78	66	72	1.97	2.10	2.04
89W795	1.80	4.11	2.95	77	65	71	1.67	1.92	1.80
89W790	2.48	3.11	2.80	75	66	71	1.37	1.36	1.37
89W796	2.07	3.44	2.75	78	64	71	1.78	2.17	1.98
Control									
ICSV 1063 BF	1.70	3.49	2.59	82	68	75	1.93	1.94	1.94
Malisor 84-1	2.18	3.87	3.02	69	61	65	1.65	2.13	1.89
Malisor 84-7	1.18	2.54	1.86	86	64	75	1.30	1.24	1.27
CSM 388	2.28	2.70	2.49	89	71	80	4.35	3.79	4.07
SE	±0.398	±0.279		±3	±1		±7	±36	
Mean (20 entries)	1.91	3.22		72	69		2.08	2.17	
CV (%)	36	15		6	4		6	29	

Breeding Hybrids

Evaluation of Female Parents

We evaluated 10 B-lines along with two improved variety controls, ICSV 1063 BF and ICSV 1079 BF, at Samanko and Cinzana. None of the female parents tested produced higher grain yields than the improved variety controls (Table 8). Time to flowering ranged from 65 to 78 days; range for plant height was limited. Two of the females, ICSB 11 and ICSB 41, have exhibited good levels of resistance to sooty stripe, anthracnose, and grey leaf spot.

Table 8. Performance of selected sorghum B-lines at Samanko and Cinzana, Mali, rainy season 1990.[1]

	Grain yield (t ha^{-1})			Time to flowering (days)			Plant height (m)		
B-Line	Samanko	Cinzana	Mean	Samanko	Cinzana	Mean	Samanko	Cinzana	Mean
ICSB 23	1.49	1.70	1.60	77	71	74	1.15	1.11	1.13
ICSB2	1.36	1.52	1.44	79	66	73	1.20	1.12	1.16
ICSB 12	1.26	1.57	1.41	78	70	74	1.27	1.11	1.19
ICSB 20	1.24	1.45	1.35	79	71	75	1.22	1.10	1.16
ICSB 21	1.03	1.62	1.33	80	71	76	1.18	1.14	1.16
ICSB 11	1.23	1.41	1.32	78	69	74	1.12	1.22	1.17
Control									
ICSV 10638 BF	2.24	2.62	2.43	79	74	77	1.88	1.85	1.87
SE	±0.159	±0.176		±1	±1		±3	±14	
Mean (12 entries)	1.30	1.62		79	70		1.28	1.20	
CV (%)	21	19		3	3		4	21	

1. Randomized block design with 3 replications, plot size 7.5 m^2 at Samanko and 8.0 m^2 at Cinzana.

Evaluation of Male Parents

Twenty-four R-lines were evaluated along with the improved variety, ICSV 1063 BF, as control, at Samanko and Cinzana. The performance of five promising lines is shown in Table 9; all yielded more than the control and will be used for producing commercial hybrids.

Table 9. Performance of selected sorghum R-lines at Samanko and Cinzana, Mali, rainy season 1990.[1]

	Grain yield (t ha^{-1})			Time to flowering (days)			Plant height (m)		
R-Line	Samanko	Cinzana	Mean	Samanko	Cinzana	Mean	Samanko	Cinzana	Mean
MR 814	1.69	2.53	2.11	84	79	82	1.63	1.70	1.67
MR 907	1.82	2.25	2.04	80	71	76	1.30	1.26	1.28
MR 913	1.87	2.17	2.02	80	72	76	1.35	1.24	1.30
MR 912	1.58	2.37	1.98	78	74	76	1.33	1.39	1.36
MR 802	1.79	1.95	1.87	81	75	78	1.67	1.73	1.70
Control									
ICSV 1063 BF	1.82	1.88	1.85	80	76	78	1.88	1.72	1.80
SE	±0.207	±0.272		±1	±1		±5	±6	
Mean (25 entries)	1.20	1.91		82	73		1.46	1.44	
CV (%)	30	25		2	3		6	7	

1. Randomized block design with 3 replications, plot size 7.5 m^2 at Samanko and 8.0 m^2 at Cinzana.

Evaluation of Hybrids

We evaluated 27 sorghum hybrids in which high-yielding breeding lines selected in West Africa were used as male parents. The six best hybrids all produced grain yields higher than the best control hybrid, ICSH 507 IN (Table 10); these six are now proposed for inclusion in the West African Sorghum Hybrid Adaptation Trial (WASHAT) in 1991.

Table 10. Performance of selected sorghum hybrids at Samanko, Mali, rainy season 1990.[1]

Hybrid	Grain yield ($t\ ha^{-1}$)	Time to flowering (days)	Plant height (m)
ICSA 1 × ICSV 1083 BF	3.05	78	2.28
ICSA 1 × BF 82-4/4-1-1	2.95	74	2.00
ICSA 39 × BF 82-4/4-1-1	2.87	75	2.58
ICSA 23 × BF 80-10/6-2-3	2.79	71	1.98
ICSA 20 × BF 80-10/6-2-3	2.77	69	1.88
ICSA 1 × ICSV 1063 BF	2.69	72	1.90
Control			
ICSH 507 IN	2.66	72	1.80
ICSV 1063 BF	2.24	78	2.07
CSM 388 (local)	1.65	81	4.03
SE	±0.452	±2	±17
Mean (30 entries)	2.37	74	2.06
CV (%)	33	4	8

1. Randomized block design with 3 replications; plot size 11.24 m^2.

Resource Management

Striga Agronomy

Parasitic Species in Mali

A manual for identification of important plant parasites of crops was prepared. Computer software for data analysis was developed in collaboration with G. Salle (University Pierre et Marie Curie, Paris), A. Raynal (Musée national d'histoire naturelle, Paris), I. Kassambara (Computer Scientist), and A. Cadic (Biologist). This will permit diagnosis of important parasitic species and cultural practices that favor their spread.

In surveys conducted in three villages located in the main agroecological regions of Mali, six parasitic species were recorded; of these, *Striga hermonthica* (Del. Benth.) is the most destructive, parasitizing all major cereal crops–sorghum, millet, maize, and rice.

The parasites are remarkably well adapted to their host plants and their environment. Although no field in our surveys was found totally infested–across the three villages actual infestation averaged about 10% of the cultivated area–about 50% of all fields showed some parasitic infestation. This indicates the seriousness of the problem; farmers rarely practice any control methods, and the rest of the culltivated area will also be at risk unless the spread of the parasites is prevented.

Integrated Control of *S. hermonthica*

Three sorghum varieties and three *Striga* control methods have been tested for 2 years, and studies on the effect of crop rotation on the parasite are also being conducted. In 1990, sorghum was grown on land that had been cropped with groundnut the previous year. Sorghum was fertilized with 5 t ha^{-1} FYM and 50 kg ha^{-1} urea.

Striga plant number per square meter was higher in 1990 than in 1989 (Fig. 1). In 1989, sorghum variety ICSV 1063 had reduced emergence of the parasite, but in 1990, with the generally higher infestation, we could detect no differences among varieties.

Whatever the method used, checking the parasite improved sorghum yields, which were 60% higher than the yield of the control. In 1989, the herbicide 2-4-5 T gave the best control of the parasite, with the least number of emerged *Striga*; in 1990, hand pulling of *Striga* gave the best control. Mulching reduced vegetative development of the parasite but did not hamper reproduction. Therefore we consider that the most effective control would be achieved by combining an early herbicide (70 DAS) with a late hand pulling (85 DAS). It is too early to evaluate the effect of crop rotation on *Striga* infestation.

Soil Solarization

In 1990 we repeated the 1989 trial on the effect of soil solarization on *Striga* (ICRISAT West African Programs Annual Report 1989, p. 99), covering the wet soil with polythene sheet for 15 and 35 days in April-May. The 35-day treatment significantly reduced *S. hermonthica* number in both years (from 73 [control] to 16 in 1989 and from 58 [control] to 5 in 1990) and significantly increased sorghum yield in 1989 but not in 1990, when trial results had a very high CV.

Agrophysiology

Response of Sorghum to Intercropping with Groundnut

We compared five sorghum varieties at Samanko, sole-cropped and intercropped with groundnut: Malisor 84-7, a short-statured variety from ICRISAT/Mali; ICSV 1049, ICSV 1063, and ICSV 1079; and CSM 388, a tall local improved variety.

Effect of cropping system on sorghum. Sole-cropped ICSV 1049 yielded the highest; Malisor 84-7, the least. There was a significant interaction between genotype and cropping system: ICSV 1049, ICSV 1063, and Malisor 84-7 yielded less when intercropped than when sole-cropped; however, ICSV 1079 and CSM 388 adapted well to intercropping and gave similar yields under both systems.

Effect on groundnut. Groundnut yielded more (1.63 t ha^{-1} pods) when intercropped with sorghum cv Malisor 84-7 than with CSM 388 (0.92 ha^{-1}) or ICSV 1049 (0.81 t ha^{-1}), these two being the most competitive sorghum varieties. However, none of the intercrop yields were comparable with the sole-crop groundnut yield of 1.63 t ha^{-1}.

Land-equivalent ratios. The intercrops were slightly more productive than sole crops, with land-equivalent ratio (LER) ranging between 1.16 and 1.53. Intercrops with ICSV 1079 and CSM 388 gave the best LERs—1.53 and 1.43, respectively. Malisor 84-7, does not compete well with groundnut; although groundnut productivity was high with this combination, sorghum yield was inadequate (LER 1.36). The variety best adapted to intercropping was ICSV 1079; its intercrop yield was double that of Malisor 84-7, while groundnut yield was not significantly different from that obtained with Malisor 84-7.

Rotation of Sorghum with Legumes

Different rotations including sorghum and legumes (cowpea, groundnut, and soybean) as sole crops or intercrops and cotton were studied at Samanko and Longorola during 1989 and 1990. Different levels of fertilization were also

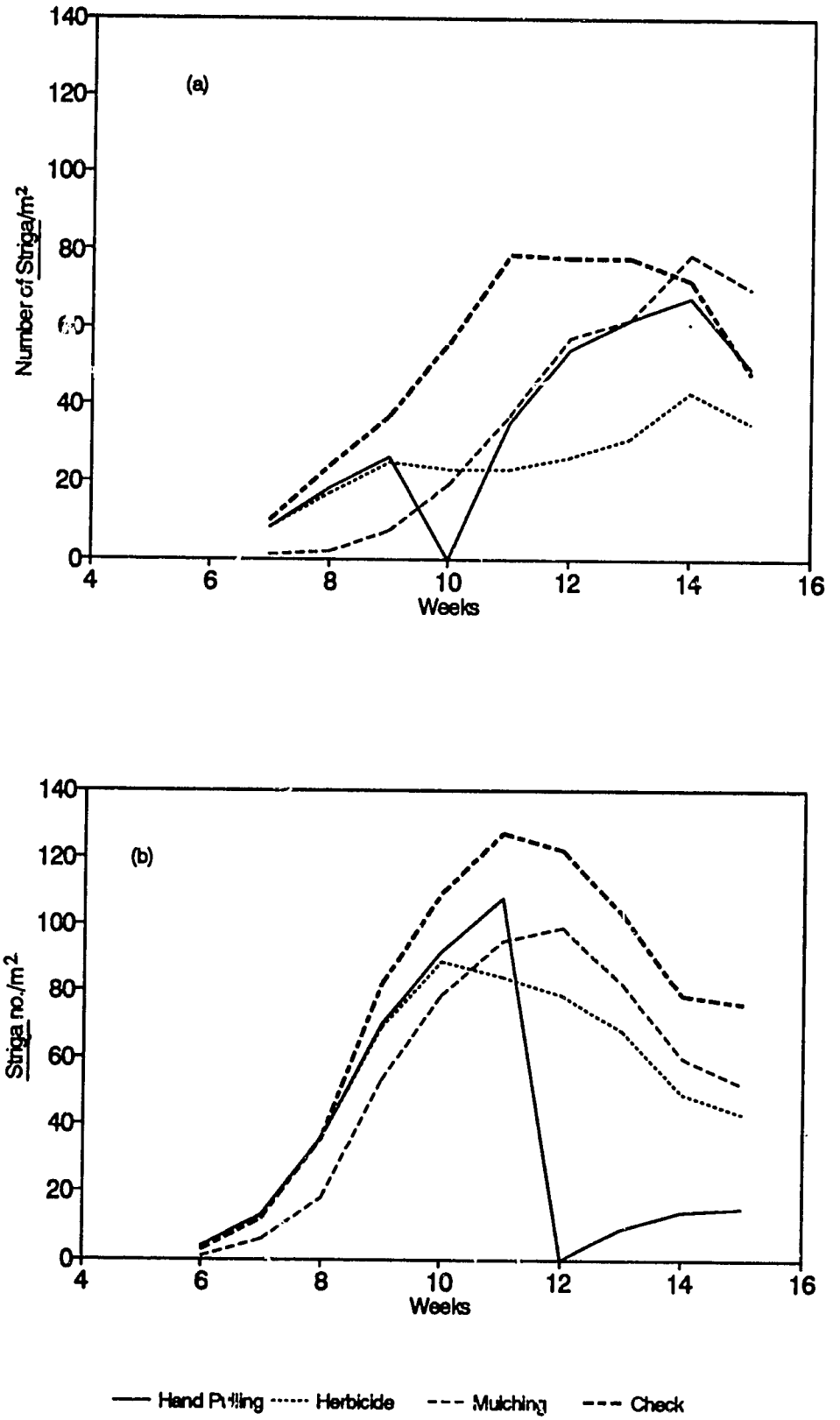

Figure 1. Dynamics of *Striga hermonthica* emergence with three methods of control; a. in 1989; b. in 1990.

compared: no added fertilizer, mineral fertilizer in amounts recommended for each crop, and mineral plus organic fertilizer (5 t ha^{-1} compost).

The principal conclusions were:

- Sorghum had no allelopathic effect on itself, and both cotton and sorghum had similar effects on yield of following sorghum;
- A sole-crop legume was the best crop to precede sorghum; the legume-sorghum rotation gave 20-30% higher sorghum grain yields than the sorghum-sorghum rotation and also increased sorghum dry-matter production (Table 11);
- The legume/sorghum intercrop had no effect on succeeding sorghum yield; however, it did have a significant effect on succeeding cotton yields where no fertilizer or only mineral fertilizer was used;
- Sorghum/legume intercrops grown on the same plots for 2 years maintained their yield advantage over sole crops; LERs for the intercrops ranged from 1 to 1.4;
- However, when sorghum/legume intercrops were compared with sole-cropped sorghum-legume rotations, we found that (a) the legume had a significant residual effect on succeeding sorghum: the rotation of legume (year 1)-sorghum (year 2) gave 75-93% higher sorghum grain yield at Samanko than the sorghum/legume intercrop rotation; (b) the sorghum/legume intercrop rotation produced more legume grain yield (up to 50% more for soybean) than the legume-sorghum sole-crop rotation (Table 12).

Agroeconomics

The village-level study program of WASIP/Mali started in June 1989 with the primary objectives of: (1) understanding the production systems in cotton-based and other cropping systems of Mali, (2) characterizing farmer resource endowment patterns and utilization in production, (3) diagnosing resource constraints to increased cereal production in these systems, and (4) testing new sorghum technologies on farmers' fields to determine productivity under on-farm conditions. Research activities during the first year covered only the noncotton systems of the Upper Niger Valley (OHV) zone; two villages, Dibaro and Nankilabougou, were selected for study.

In 1990, the program was extended into the cotton-based cropping systems in the CMDT zone in southern Mali, and two new villages, Garasso and Siramana, were selected in the regions of Koutiala and Sikasso, which account for the major share of cotton production in Mali.

Table 11. Residual effect of preceding crop on sorghum grain and dry-matter production in Mali, 1990.[1]

Preceding crop (1989)	Sorghum grain yield (t ha^{-1})		Sorghum dry-matter production (t ha^{-1})[2]	
	Samanko	Longorola	Straw	Total dry-matter
Sole crop				
Sorghum	1.71 ab	1.06 b	5.05 b	7.57 b
Groundnut	1.98 a	1.41 ab	7.53 a	10.41 a
Cowpea	1.68 ab	1.75 a	6.70 ab	9.23 ab
Soybean	1.85 a	1.35 ab	6.73 ab	9.41 ab
Intercrop				
Sorghum/groundnut	1.53 ab	1.19 b	6.39 ab	8.72 ab
Sorghum/cowpea	1.38 b	1.52 ab	5.52 b	7.79 b
Sorghum/soybean	1.61 ab	1.25 ab	6.00 ab	8.50 ab
SE (preceding crop)	±0.111	±0.128	±0.468	±0.573
CV (%)	18.7	26.7	21.1	18.4

1. Randomized block design with 4 replications.
2. Dry-matter production measured only at Samanko.
3. Means followed by the same letter in a column are not significantly different (P<=0.05).

Table 12. Total production in 2 years of different sorghum-legume crop rotation with no added fertilizer, Mali, 1989/90.

Location	Rotation		Total yield over 2 years (t ha^{-1})	
	Year 1	Year 2	Legume	Sorghum
Somanko	Groundnut	Sorghum	1.16	1.93
	Sorghum/groundnut	Sorghum/groundnut	1.15	1.00
	Cowpea	Sorghum	0.57	1.83
	Sorghum/cowpea	Sorghum/cowpea	0.65	1.05
	Soybean	Sorghum	0.88	1.81
	Sorghum/soybean	Sorghum/soybean	1.32	1.03
Longorola	Groundnut	Sorghum	1.20	1.23
	Sorghum/groundnut	Sorghum/groundnut	1.64	1.07
	Soybean	Sorghum	1.05	1.35
	Sorghum/soybean	Sorghum/soybean	1.51	1.07

In the two villages of the OHV zone, we selected a random sample of 40 farmers (20 per village) in two categories (10 farmers for each), as in 1989: (1) households using oxen tillage (equipped and semi-equipped households), defined as households with at least a pair of oxen, a plow, and/or a multipurpose plow and (2) households using hand tillage (manual households).

In the two villages of the CMDT zone, we selected 60 farmers (30 per village), according to the farm type. These types have been described as follows: (A) those with at least two pairs of oxen, one plow, one multipurpose plow, one seeder, one cart, and at least 10 head of cattle (well-equipped farmers); (B) those with at least one pair of oxen and one plow or multipurpose plow (equipped farmers); (C) those with one unit of incomplete animal traction implements (semi-equipped farmers) and (D) those with no animal traction implements, relying on the traditional hoe for cultivation (manual farmers).

In Garasso, 10 farmers each from types A, B, and D were surveyed; in Siramana, 11 farmers from type A, 15 from type B, and 4 from type D were surveyed.

One field technician was posted in each study village to visit the survey farmers daily to collect data. Two questionnaires–one on cultivation techniques and resource utilization and one on socioeconomic characteristics of the household–were administered to the farmers; these are now being sorted and data from them being entered in the computer.

Preliminary analysis of data on cultivated areas and yields has been done to determine cropping intensities across the two zones, and average yields under alternative cropping systems in the four villages. In the OHV zone, percentage of the total cultivated area is highest for sorghum, followed by pearl millet, groundnut, and maize. Pearl millet cropping intensity decreases from the OHV to the CMDT zone (Table 13). Maize cultivation is more important in the CMDT than in the OHV zone, even allowing for the fact that we did not take into account all data for maize fields in Dibaro, where the crop failed because of drought in August 1990 (total rainfall 46.8 mm). The most important crop in the CMDT zone, based on area cultivated, is cotton, followed by sorghum.

Our village-level studies in 1989 had shown that sorghum remains the major crop for agricultural households in both the Sudanian and the Northern Guinean Zones, and results in 1990 confirm this. Maize and cotton yields are determined by farm type (Table 14), with average yields being highest on type A farms, followed, in that order, by type B, C, and D farms. Sorghum average yields also depend on cropping system practiced–for all four farm types, sorghum yields were higher in the sorghum sole crop than in the sorghum/cowpea intercrop.

The Agroeconomics subprogram of WASIP/Mali, in collaboration with the Agronomy subprogram, also conducted on-farm tests of sorghum technology in the four villages selected for the village-level studies. The objective of these tests was to compare the performance at the farm level of two ICRISAT sorghum varieties (ICSV 1063 and ICSV 1079) and an improved local variety from the national research program of Mali (CSM 388) with that of the local farmers' variety used in sorghum/groundnut intercrops in this region. Analysis of collected data is in progress.

Table 13. Principal cereal and cash-crop area as a percentage of total cropped area in the CMDT and OHV zones of Mali.[1]

	Percentage of total cultivated area					
Zone	Sorghum	Millet	Maize	Groundnut	Cotton	Rice
CMDT	33	11	18	1	36	-
OHV	61	19	2[2]	6	-	1

1. In the four villages chosen for the Agroeconomics study : Dibaro and Nankilabougou in the OHV zone; Garasso and Siramana in the CMDT zone.
2. Data were collected for only 1 maize field in Dibaro, all other maize crops failed due to lack of rain in August 1990 and were abandoned by the farmers.

Table 14. Average crop yields under various cropping systems by farm type (average of four villages), OHV and CMDT zones, Mali.

	Yield (t ha^{-1})			
	Farm Type[1]			
Cropping system	A	B	C	D
Maize sole crop	2.50 (1.10)[2]	1.90 (1.10)	1.40 (0.42)	1.50 (1.20)
Maize/millet intercrop	-	-	-	0.70 (0.26)
Maize/sorghum intercrop	-	-	1.30 (0.05)	-
Sorghum sole crop	0.87 (0.45)	0.91 (0.39)	0.95 (0.33)	0.96 (0.42)
Sorghum/cowpea intercrop	0.83 (0.44)	0.71 (0.27)	0.73 (0.46)	0.59 (0.23)
Pearl millet sole crop	0.59 (0.44)	0.54 (0.29)	-	0.60 (0.26)
Millet/cowpea intercrop	0.52 (0.14)	0.61 (0.26)	-	-
Groundnut sole crop	0.82 (0.35)	0.70 (0.25)	0.77 (0.32)	0.70 (0.20)
Cotton sole crop	1.76 (0.63)	1.64 (0.70)	-	1.20 (0.49)

1. Farm classification of the farming systems research unit of WASIP, Mali. A: "well-equipped" farmers with at least two pairs of oxen, one plow, one multipurpose plow, one seeder, one cart, and at least 10 head of cattle; B: "equipped" farmers with at least one pair of oxen and one plow or multipurpose plow; C: "semi-equipped" farmers with one unit of incomplete animal traction implements; they know how to use but must borrow the equipment; D: "manual" farmers with no animal traction implements; relying on the traditional hoe.
2. Values in parentheses are standard deviations of corresponding yields.

Cooperation with National Programs

West and Central Africa Sorghum Research Network (WCASRN)

Regional Adaptation Trials (1989)

The West African Sorghum Variety Adaptation Trial (WASVAT-89)—conducted through the WCASRN in 1989—comprised short- and medium-duration entries in separate trials. Each trial consisted of 20 entries contributed by WASIP and by the national programs of Benin, Burkina Faso, Cameroon, Ghana, Mauritania, Niger, and Sénégal. Mean yield for WASVAT short-duration entries from 10 locations ranged from 1.27 to 2.85 t ha^{-1}. Cv ICSV 1079 had the second highest overall mean yield of 2.74 t ha^{-1}, followed by CS 61 (2.65 t ha^{-1}) and ICSV 111 IN (2.55 t ha^{-1}). One of the controls, Nagawhite, gave the highest mean yield (2.85 t ha^{-1}) (Table 15). In the medium-duration trial, ICSV

Table 15. Mean grain yield (t ha^{-1}) of the highest-yielding short-duration cultivars in the West African Sorghum Variety Adaptation Trial (WASVAT) at 10 locations in West Africa[1], rainy season 1989.

Entry	1 Mean	2 Mean	3 Mean	4 Mean	5 Mean	6 Mean	7 Mean	8 Mean	9 Mean	10 Mean	Overall mean
ICSV 1079 BF	2.84 (2)	3.18 (2)	3.24 (7)	2.29 (4)	2.40 (6)	2.74 (13)	4.83 (2)	3.18 (1)	1.45 (1)	2.71 (3)	2.74 (1)
CS-95	2.94 (4)	1.94 (18)	3.54 (2)	2.40 (1)	1.93 (11)	3.24 (8)	4.98 (1)	2.96 (3)	1.25 (3)	2.57 (5)	2.65 (2)
ICSV 111 IN	2.38 (9)	2.70 (7)	3.16 (9)	1.99 (10)	1.60 (16)	3.33 (7)	4.73 (3)	2.72 (6)	1.37 (4)	2.89 (1)	2.55 (3)
ICSV 1172 BF	2.55 (7)	3.16 (3)	3.25 (6)	1.83 (14)	2.00 (10)	3.46 (5)	4.59 (4)	2.48 (9)	0.46 (19)	2.28 (11)	2.47 (4)
CS-54	2.73 (6)	2.68 (8)	3.28 (5)	1.91 (13)	2.02 (9)	2.69 (14)	3.96 (10)	2.84 (4)	1.12 (5)	2.79 (2)	2.45 (5)
ICSV 1177 BF	2.10 (12)	3.46 (1)	3.10 (10)	2.40 (3)	1.90 (12)	2.75 (12)	3.90 (13)	2.03 (15)	0.94 (9)	2.71 (3)	2.44 (6)
ICSV 1176 BF	3.03 (3)	2.75 (6)	2.60 (16)	2.03 (8)	2.67 (4)	3.42 (6)	3.84 (14)	2.51 (8)	0.80 (11)	2.11 (13)	2.40 (7)
ICSV 401 IN	3.17 (2)	2.44 (13)	2.61 (15)	2.16 (6)	2.48 (5)	2.61 (15)	4.29 (6)	2.97 (2)	0.96 (8)	1.90 (15)	2.38 (8)
ICSV 1125 BF	2.13 (10)	2.54 (10)	2.81 (12)	1.92 (12)	1.79 (13)	3.50 (3)	4.47 (4)	2.41 (10)	0.72 (15)	2.23 (12)	2.37 (9)
Control											
Nagawhite	2.73 (6)	2.95 (4)	3.75 (1)	2.67 (1)	2.73 (3)	5.49 (1)	4.15 (8)	2.51 (8)	0.75 (14)	2.49 (10)	2.85 (1)
Local	2.01 (14)	2.28 (15)	3.38 (3)	1.72 (17)	2.17 (7)	4.53 (2)	3.93 (11)	2.75 (5)	0.83 (10)	2.67 (4)	
SE	±0.32	±0.20	±0.18	±0.18	±0.26	±0.43	±0.36	±0.14	±0.29	±0.21	
Trial mean (20 entries)	2.30	2.55	2.95	2.06	1.96	2.93	3.92	2.27	0.88	2.40	
CV (%)	24	18	11	15	23	225	16	22	28	26	

1. Locations: 1 = Farako-Bâ; 2 = Saria in Burkina Faso; 3 = Guiring in Cameroon; 4 = Cinzana; 5 = Samanko in Mali; 6 = Maradi in Niger; 7 = Bagauda in Nigeria; 8 = Nyankpala; 9 = Manga Bawku in Ghana; 10 = Bambey in Senegal.
2. Randomized-block design with 3 replications, plot size ranged from 5.5 m² to 14.4 m². Local control different at each location.
3. Values in parentheses are ranks.

1171 BF gave the highest mean yield (2.37 t ha^{-1}) over nine locations followed by F2-20 (2.34 t ha^{-1}) and CS 95 (2.32 t ha^{-1}) (Table 16).

The West African Sorghum Hybrid Adaptation Trial (WASHAT-89) had 20 entries. Results from eight locations indicated that the highest yielding hybrids were ICSH 507 (3.66 t ha^{-1}), ICSH 780 (3.60 t ha^{-1}), and the hybrid from the national program of Niger Tx623 × MR732 (3.58 t ha^{-1}) (Table 17).

WCASRN Steering Committee Meetings

The seventh steering committee meeting of the WCASRN was held in Niamey, Niger, 2-4 May 1990. One of the decisions taken was that the national program of Niger should submit a project proposal on sorghum grain quality. At the eighth steering committee meeting in Bamako, Mali, 3-4 Dec 1990, it was decided that WASIP/Mali should organize a 2-week in-service training course on plant protection for researchers in three NARS. Financial support for research and other activities related to sorghum was increased for 1991.

Visits to NARS. During 1990, the steering committee members visited Ghana and Benin. The Coordinator visited Burkina Faso, Chad, Guinea, Niger, Nigeria, and Sierra Leone. A standard terms-of-reference form was prepared for all such visits to national program research facilities.

Research Projects with National Programs

Four projects funded by the WCASRN and conducted by national program research scientists were reviewed at working group meetings held at WASIP/Mali (19-20 Apr 1990) and the Institute for Agricultural Research (IAR), Ahmadu Bello University, in Zaria, Nigeria. Principal investigators of the projects, evaluators from the national programs of Niger and Mali, and resource persons from FAO in Mali, WASIP/Nigeria, and WASIP/Mali discussed the first year's results and plans for the future.

1. Leaf anthracnose (Burkina Faso): Resistance to this disease in some local and introduced sorghum genotypes was confirmed for the second year. Improved genotypes showed a higher percentage of seed infected with anthracnose fungus than local ones.
2. Long smut (Niger): Preliminary results from this project indicated a positive correlation between degree of infection and maturity cycle. Early sowing reduced the incidence of this disease.
3. Head bugs (Mali): Resistance to head bugs found in some local and introduced sorghum genotypes was confirmed for the second year. Population dynamics studies of larvae and nymphs confirmed that there were two peaks in head bug infestation during the season.
4. Wheat-sorghum composite flour (Nigeria): Shelf-life studies showed that bread made from composite flour with 50% sorghum can be kept for only 2 days without signs of deterioration. Acceptable quality snacks could be made with 60% sorghum substitution.

Training

Six Ingenieur Agronome final year students from the Institut polytechnique rural of Katibougou successfully completed 7 months' research training and submitted theses in the fields of agrophysiology, *Striga* agronomy, entomology, and plant breeding.

Table 16. Mean grain yield (t ha^{-1}) of the highest-yielding medium-duration cultivars in the West African Sorghum Variety Adaptation Trial (WASVAT) at nine locations in West Africa[1], rainy season 1989.

Entry	1 Mean	2 Mean	3 Mean	4 Mean	5 Mean	6 Mean	7 Mean	8 Mean	9 Mean	Overall mean
ICSV 1171 BF	3.71 (1)	2.74 (2)	1.84 (1)	1.20 (4)	2.71 (3)	4.03 (3)	2.68 (8)	4.83 (1)	0.18 (11)	2.37 (1)
F2-20	2.91 (9)	2.78 (1)	1.32 (8)	1.32 (2)	2.73 (2)	3.50 (6)	2.41 (11)	4.45 (5)	0.32 (3)	2.34 (2)
CS-95	2.45 (13)	2.66 (3)	1.63 (3)	1.30 (3)	2.50 (7)	4.35 (1)	2.58 (9)	4.78 (2)	0.42 (1)	2.32 (3)
ICSV 1089 BF	2.94 (8)	1.97 (12)	1.51 (5)	1.00 (8)	2.42 (9)	3.45 (7)	2.81 (7)	4.03 (10)	0.07 (15)	2.29 (4)
SEPON-82	3.32 (2)	2.35 (6)	1.67 (2)	1.15 (5)	2.65 (5)	4.31 (2)	2.93 (4)	4.44 (6)	0.18 (11)	2.25 (5)
ICSV 1163 BF	3.03 (6)	2.42 (5)	1.54 (4)	1.32 (2)	2.23 (12)	3.73 (4)	2.83 (6)	4.74 (3)	0.24 (6)	2.17 (6)
BF-82-4/4-1-1	2.95 (7)	2.29 (8)	1.39 (7)	1.20 (4)	2.83 (1)	2.38 (12)	2.41 (11)	4.14 (9)	0.22 (7)	2.14 (7)
ICSV 1063 BF	2.65 (11)	2.19 (10)	1.40 (6)	1.13 (6)	2.58 (6)	3.38 (8)	3.38 (2)	3.83 (11)	0.21 (8)	2.11 (8)
ICSV 1157 BF	2.64 (12)	2.32 (7)	0.68 (14)	1.12 (7)	2.17 (13)	3.63 (5)	2.50 (10)	4.32 (7)	0.26 (5)	2.06 (9)
Control										
Local	2.35 (14)	2.65 (4)	1.31 (9)	1.39 (1)	1.44 (16)	1.79 (14)	0.26 (19)	4.16 (8)	0.24 (6)	
SE	±0.31	±0.26	±0.19	±0.15	±0.22	± 0.32	±0.37	±0.17		
Trial mean (20 entries)	2.67	2.00	1.11	0.89	2.04	2.76	2.32	3.89	0.20	
CV (%)	20	22	30	30	18	20	28	13	25	

1. Locations: 1 = Farako-Bâ; 2 = Saria in Burkina Faso; 3 = Manga Bawku in Ghana; 4 = Sotuba; 5 = Samanko in Mali; 6 = Bengou in Niger; 7 = Bagauda in Nigeria; 8 = Nioro in Senegal; 9 = Tangiegou in Togo.
2. Randomized-block design with 3 replications, plot size ranged from 6.0 m^2 to 14.4 m^2. Local control different at each location.
3. Values in parentheses are ranks.

Table 17. Mean grain yield (t ha^{-1}) of selected hybrids in the West African Sorghum Hybrid Adaptation Trial (WASHAT) at eight locations in West Africa, rainy seaon 1989.[1]

Entry	1 Mean	2 Mean	3 Mean	4 Mean	5 Mean	6 Mean	7 Mean	8 Mean	Overall mean
ICSH 507	3.40 (7)	2.93 (11)	4.84 (2)	1.70 (8)	5.48 (1)	7.64 (2)	2.08 (2)	1.22 (8)	3.66 (1)
ICSH 780	3.32 (10)	3.40 (5)	3.48 (17)	2.74 (4)	5.43 (2)	7.54 (3)	1.43 (8)	1.47 (4)	3.60 (2)
Tx623 × MR732	3.71 (1)	3.07 (7)	5.33 (1)	2.92 (1)	4.33 (14)	6.95 (11)	1.34 (11)	1.03 (11)	3.58 (3)
ICSH 89002	3.41 (6)	3.51 (3)	4.41 (6)	1.67 (10)	4.92 (6)	7.98 (1)	1.51 (3)	1.14 (9)	3.57 (4)
ICSH 89001	2.33 (19)	2.98 (10)	4.27 (8)	2.29 (3)	4.89 (7)	7.06 (9)	2.09 (1)	1.79 (2)	3.46 (5)
ICSH 479	3.54 (4)	2.89 (12)	3.61 (14)	1.81 (7)	5.23 (4)	7.21 (5)	1.02 (17)	1.56 (3)	3.36 (6)
Control									
ICSH 109	2.69 (16)	3.09 (9)	4.55 (4)	1.81 (7)	4.21 (15)	6.00 (17)	1.06 (16)	0.49 (18)	2.99 (17)
ICSH 111	2.44 (18)	3.00 (8)	3.55 (16)	1.63 (11)	3.34 (17)	6.07 (16)	1.95 (3)	1.82 (1)	2.98 (18)
Local	3.07 (12)	1.44 (18)	3.62 (13)	1.08 (14)	4.69 (10)	6.65 (13)	1.08 (15)	0.93 (13)	
SE	±0.55	±0.31	±0.37	±0.53	±0.81	±0.54	±0.39	±0.41	
Trial mean (20 entries)	3.06	2.88	3.93	1.77	4.49	6.80	1.33	1.09	
CV (%)	18	11	16	30	18	8	30	37	

1. Locations: 1 = Sotuba in Mali; 2 = Samanko in Mali; 3 = Tarna in Niger; 4 = Lossa in Niger; 5 = Bagauda in Nigeria; 6 = Guiring in Cameroon; 7 = Bouaké in Cote d'Ivoire; 8 = Farako-Bâ in Burkina Faso.
2. Randomized-block design with 3 replications. Local control different at each location.
3. Values in parentheses are ranks.

West African Sorghum Improvement Program/Nigeria

Weather

Monthly temperature and rainfall data for the West African Sorghum Improvement Program/Nigeria (WASIP/N) farm at Bagauda for 1990 are shown in Figure 1. Total rainfall for the year was 556 mm–37% below the long-term average for Kano. The rains in May and June were scanty and scattered. Farmers who took the risk and sowed early suffered problems of establishment in some localities. The first planting rains occurred at Bagauda on 6 July. The rains in July and the first 2 weeks of August were well distributed and near average, however, little rain fell in the later part of August, so the monthly total was 53% below average. Heavy rains (72.5 mm) on 11-14 September relieved the serious threat of drought. While good yields (4-5 t ha^{-1}) were obtained from early-maturing cultivars, severe lodging was observed in some lines.

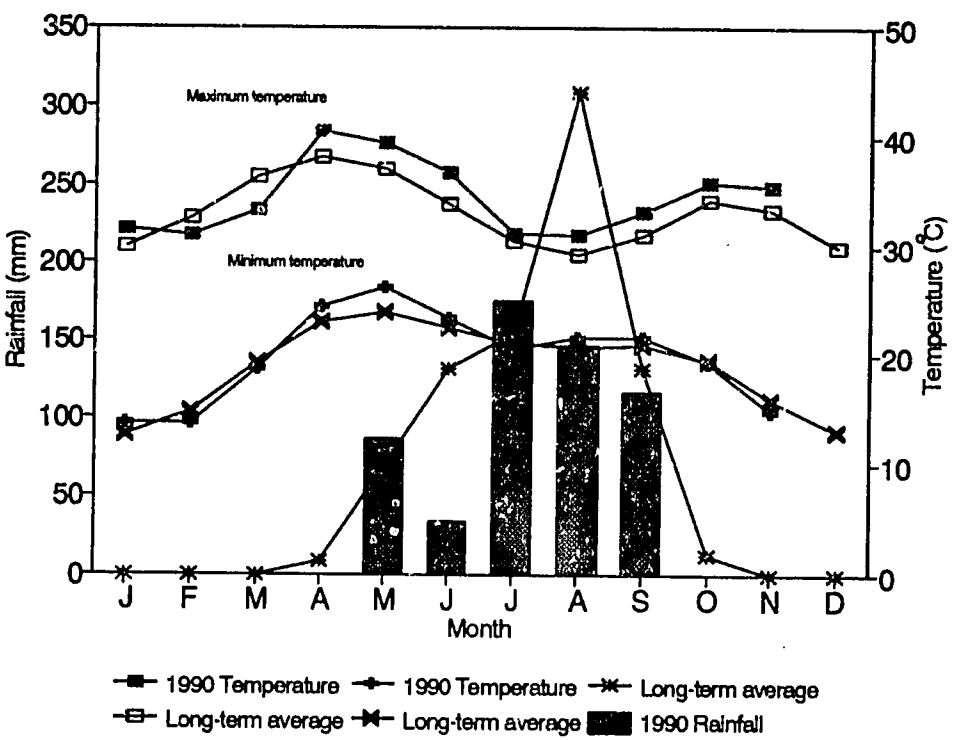

Figure 1. Monthly mean maximum and minimum air temperature and rainfall for Bagauda 1990 and long-term averages for Kano, Nigeria.

Abiotic Stresses

Terminal Drought

Local landraces of sorghum represent a valuable genetic resource for use in plant-breeding programs, as they are often a source of resistance to many abiotic and biotic stress factors. A major abiotic stress in northern Nigeria is terminal drought. Landraces often fill grain under conditions of terminal drought stress, as flowering is timed to coincide with the end of the rains. Thus these local landraces may be a potential source of drought resistance. The physiology unit has therefore initiated a series of studies to determine the extent of terminal drought resistance present in West African landraces.

Thirty-six local sorghum lines were obtained from the Kano State Agricultural Development Project; they comprised white - (Farafara), yellow - (Kaura), and red-seeded types, many with bold grain. Plant height was linearly related to time to flowering and ranged from 2 to 4 m. Flowering occurred from 55 to 120 days after sowing (DAS), depending on the origin and photoperiod sensitivity of the material. The maximum leaf area index of the crops increased from 0.9 to 3.1 as time to flowering increased from 55 to 80 DAS. In later-flowering lines, leaf area index fell as a result of the prevailing drought conditions. During the period between 39 and 71 DAS, all cultivars converted radiation into biomass with an efficiency of about 1.7 g MJ^{-1}.

The harvest index (proportion of total dry mass in the grain) was high (0.45) in early-maturing lines, falling to 0.32 as flowering was delayed to 80 DAS (Fig. 2). Crops that flowered later than 80 days suffered from terminal drought

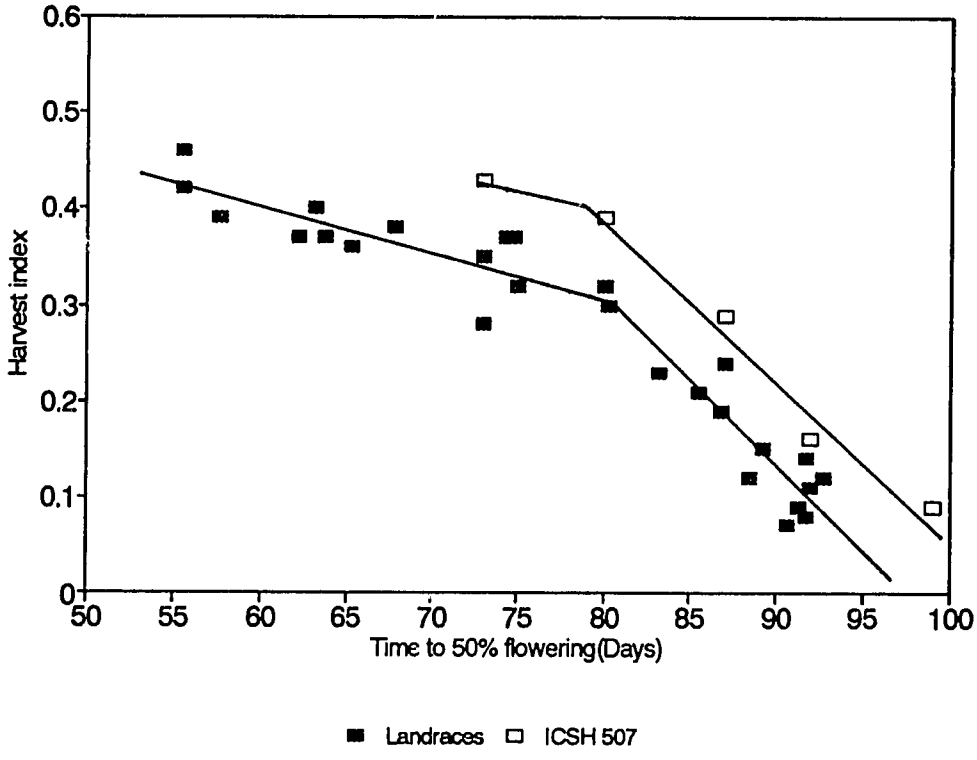

Figure 2. Relationship between time to flowering and harvest index of a sorghum hybrid and local landraces.

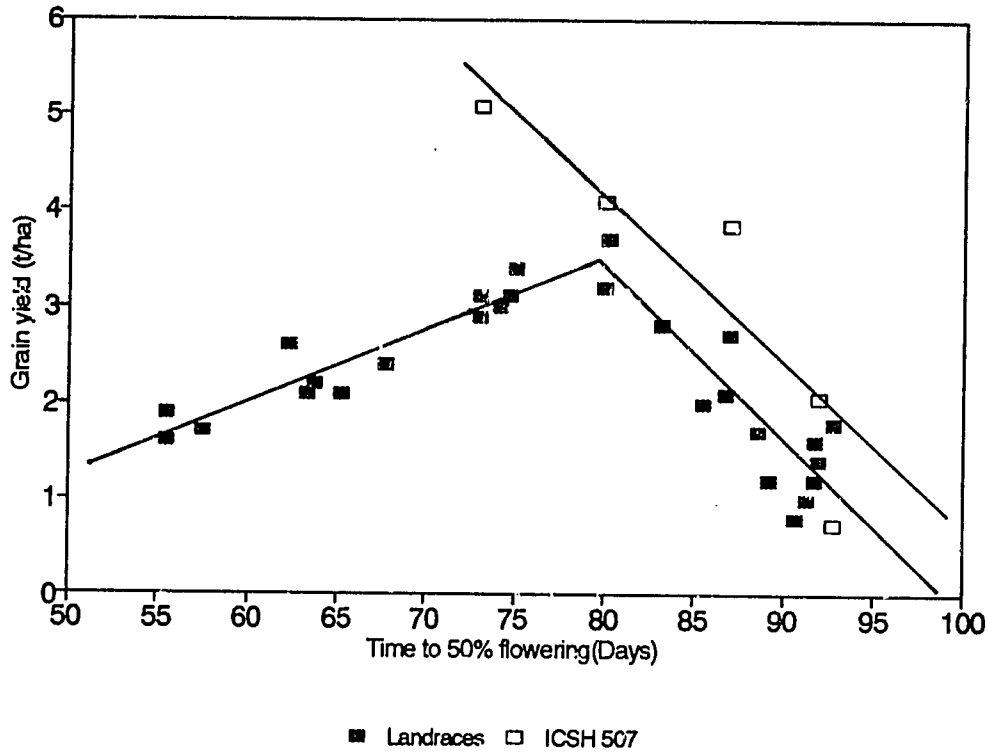

Figure 3. Relationship between grain yield and time to flowering of a sorghum hybrid and local landraces.

stress, and harvest index fell drastically (from 0.32 to 0). Grain yields of early-maturing landraces were low (1.5 t ha^{-1}), despite their high harvest indices, due to their poor interception of radiation (Fig. 3). Grain yields reached a maximum of 3.5 t ha^{-1} in crops that flowered at 80 days. The drastic decline in harvest index in later-maturing lines was the direct result of poor grain-filling due to terminal drought.

Promising ICRISAT sorghum hybrids, such as ICSH 507, because they are early-maturing, escape the effects of terminal drought. In order to study the effects of terminal drought stress on this material and to compare it with the later-maturing local material, an experiment was conducted using a range of sowing dates. The first planting rains occurred at Bagauda on 6 Jul 1990 and crops were sown 6, 13, 20, 25, and 32 days later at a density of 10.7 plants m^{-2}. All crops flowered 66.5 DAS and there was little difference in plant height (1.6 m), indicating that the stress occurred predominantly during the grain-filling period.

The high harvest index of the hybrid (0.45) was substantially higher than landraces of a similar maturity (Fig. 2). When sowing was delayed, crops that flowered later than 80 days after the first planting rains suffered a drastic reduction in harvest index, as did the landraces. Crops that flowered later than 100 days gave negligible yield. Yields decreased from 5.1 to less than 1 t ha^{-1} as sowing was delayed from 6 to 32 days. This decrease in yield as a result of terminal drought stress was similar in both ICRISAT hybrid and local landraces. Associated measurements of soil water balance of ICSH 507 and selected landraces will provide further useful data in comparing the performance of this contrasting material in the Kano environment.

Crop Density and Fertilizer Effects

In 1989, we initiated a study to determine the optimum crop density for newly developed sorghum cultivars grown in the Sudanian Zone of West Africa. We reported (ICRISAT West African Programs Annual Report 1989, p. 108) that a density of 10.6 plants m^{-2} gave the highest grain yields for all three sorghum cultivars tested. During 1990, we continued the studies on crop density effects on sorghum and included fertilizer effects. Measurements (data not reported here) of water use, radiation interception, and dry-matter partitioning into plant parts will enable a better understanding of the mechanisms determining the response of sorghum to various crop densities and fertility levels in this environment.

In a trial sown on 10 July 1990, we investigated the effects of five crop densities on the performance of an improved variety, ICSV 247; a hybrid, ICSH 507; and a tall, late, locally recommended variety, Samsorg 14. Table 1 shows the five crop densities and the results. Grain yields of all three cultivars decreased as plant density increased from 2.7 to 17.8 plants m^{-2}. In contrast to the 1989 cropping season when grain yields were optimal at the plant density of 10.6 plants m^{-2}, in 1990 the optimal grain yields were achieved at a density of 5.3 plants m^{-2}, although the differences were not statistically significant. Late sowing coupled with drought in 1990 caused an overall reduction in yield, and the lack of cultivar response to higher plant density. Plant height and grain size followed the same trend as the grain yield. Samsorg 14 yielded less grain than ICSV 247 and ICSH 507, but produced more total biomass. Because of their earliness, ICSV 247 and ICSH 507 did not suffer as much from terminal drought as did Samsorg 14.

Table 1. Effect of crop density on the performance of three sorghum cultivars[1] at Bagauda, Nigeria, rainy season 1990[2].

Plant density (plants m^{-2})	Plant height (m)			100-grain mass (g)			Yield (t ha^{-1}) Grain			Yield (t ha^{-1}) Total dry matter		
	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3	V_1	V_2	V_3
2.7	1.8	1.6	2.7	2.0	2.0	2.4	2.47	2.59	0.96	7.86	7.67	11.08
5.3	1.7	1.6	2.9	2.2	2.0	2.8	2.57	2.62	1.75	8.17	7.21	9.89
10.6	1.7	1.7	3.1	2.1	2.0	2.3	2.43	2.02	1.49	8.53	8.02	12.52
13.3	1.5	1.4	2.3	1.8	1.8	2.1	1.68	1.56	0.60	7.68	6.95	9.40
17.8	1.4	1.4	1.9	1.9	1.6	2.7	1.25	1.28	0.97	6.85	8.46	9.56
SE (main plot)[3]		±0.16			±0.30			±0.647			±1.417	
Mean	1.6	1.5	2.6	2.0	1.9	2.5	2.08	2.01	1.15	7.82	7.66	10.49
SE (subplot)[4]		±0.13			±0.23			±0.282			±0.854	
CV (%)		12			19			27			17	

1. V_1 = ICSV 247, V_2 = ICSH 507, V_3 = Samsorg 14.
2. Split plot design with 3 replications, plot size 13.5 m^2.
3. SE (main plot = density) for comparing density with same level of cultivar.
4. SE (subplot = cultivar) for comparing cultivar with same level of density.

The effects of plant density and nitrogen levels on the performance of two contrasting sorghum varieties, ICSV 247 (early-maturing, medium height) and Samsorg 14 (late-maturing, tall) were studied in another trial sown on 6 July 1990. Grain yields decreased from 2.03 to 1.46 t ha^{-1} as plant density increased from 5.3 to 17.8 plants m^{-2} (Table 2). Grain yields increased with nitrogen level up to 60 kg N ha^{-1}. ICSV 247 was earlier and shorter, and had smaller grains but higher grain yield than Samsorg 14. Yields were generally low due to mid-season and terminal droughts.

Table 2. Effect of cultivar, crop density, and nitrogen levels on the performance of sorghum at Bagauda, Nigeria, rainy season 1990.[1]

Treatment	Time to 50% flowering (days)	Plant height (m)	100-grain mass (g)	Yield (t ha^{-1})	
				Grain	Total dry matter
Cultivar					
ICSV 247	71	1.6	2.1	2.26	7.74
Samsorg 14	86	2.8	2.9	1.35	9.44
SE	±0.8	±0.14	±0.05	±0.045	±0.439
Density (plants m^{-2})					
5.3	78	2.4	2.5	2.03	8.75
10.6	80	2.2	2.5	1.92	9.04
17.8	79	2.1	2.4	1.46	7.98
SE	±0.2	±0.12	±0.09	±0.072	±0.394
Nitrogen levels (kg N ha^{-1})					
0	79	1.9	2.5	1.40	6.14
30	80	2.2	2.5	1.80	8.91
60	79	2.3	2.4	2.01	9.31
90	78	2.5	2.6	2.02	10.00
SE	±1.1	±0.08	±0.09	±0.174	±0.497
CV (%)	3	15	20	36	23

1. Split-plot design with 3 replications, net plot size 18 m^2.

In collaboration with the Institute for Agricultural Research (IAR), we evaluated the performance of two new ICRISAT hybrids, ICSH 507 and ICSH 89002 NG, and one IAR hybrid, NSSH 1, as affected by crop density and nitrogen (N) levels. Samsorg 14, a tall, late-maturing IAR variety, was used as control. Sowing was delayed until 7 Jul 1990 due to the late onset of rains.

All the three hybrids flowered earlier, were shorter and produced higher grain yields than Samsorg 14; their grain size, however, was smaller than that of Samsorg 14. ICSH 507 had the highest grain yield (3. 90 t ha^{-1}), followed by ICSH 89002 NG (3.73 t ha^{-1}), NSSH 1 (2.81 t ha^{-1}), and Samsorg 14 (1.58 t ha^{-1}) (Table 3). There was no significant difference in grain yields between the two crop densities. In contrast to the 1989 season, when rainfall was adequate and uniformly distributed, grain yields in 1990 were adversely affected more at the higher density of 10.6 than at 5.3 plants m^{-2}, because of drought. There was relatively less competition for moisture at the lower density of 5.3 plants m^{-2}. All the cultivars responded significantly to increased N levels, with the highest grain yields achieved at 90 kg N ha^{-1}.

Sorghum-based Cropping Systems

Sorghum/Soybean System

In the intermediate-rainfall zones (500-900 mm) of West Africa, the sorghum/soybean system has some potential with early-maturing soybean and sorghum cultivars.

Table 3. Effect of cultivar, crop density, and nitrogen levels on the performance of sorghum at Bagauda, Nigeria, rainy season 1990.[1]

Treatment	Time to 50% flowering (days)	Plant height (m)	100-grain mass (g)	Yield (t ha^{-1}) Grain	Yield (t ha^{-1}) Total dry matter
Cultivar					
ICSH 507	61	1.7	2.3	3.90	9.56
ICSH 89002 NG	66	1.9	2.2	3.73	9.86
NSSH-1	67	1.4	2.0	2.81	8.04
Samsorg 14	88	2.9	2.8	1.58	11.28
SE	±0.4	±0.04	±0.10	±0.141	±0.325
Density (plants m^{-2})					
5.3	71	2.0	2.3	2.98	9.33
10.6	71	1.9	2.4	3.03	10.05
SE	±0.3	±0.05	±0.07	±0.217	±0.582
Nitrogen levels (kg N ha^{-1})					
0	66	1.8	2.2	2.08	7.70
45	59	2.0	2.4	3.23	9.56
90	60	2.0	2.5	3.54	11.31
135	59	2.0	2.3	3.17	10.18
SE	±0.5	±0.08	±0.09	±0.211	±0.405
CV (%)	4	17	18	32	22

1. Split-plot design with 3 replications, net plot size 15 m^2.

In continuation of our collaborative work with IITA on sorghum/soybean intercropping, we evaluated this system, using three sorghum cultivars (Sor), ICSV 247, ICSH 507, and Samsorg 14; one early-maturing soybean (Soy), TGX 1497-1 D; and three row arrangements (1Sor:1Soy; 1Sor:2Soy, and alternate stands). The trial was sown on 8 Jul 1990.

Soybean intercropped with Samsorg 14 gave a yield advantage of 26%, but gave only 1% yield advantage with ICSV 247 and ICSH 507 (Table 4). The productivity of the system was highest with the 1 Sor:2 Soy arrangement, with a land-equivalent ratio (LER) of 1.09; the alternate-stand arrangement was next highest, with a 1.06 LER. The 1 Sor:1 Soy gave no yield advantage (LER = 0.96). Drought stress reduced the grain yields of all cultivars.

Sorghum/Pigeonpea System

Pigeonpea is a multipurpose crop that can provide food, fuelwood, and fodder for the small farmer in subsistence agriculture. It also enhances soil fertility, and its deep-rooting pattern enables it to exploit available moisture at greater soil depth. Thus it is attractive and economical for the resource-poor farmer.

Table 4. Grain yield of three sorghum cultivars and a soybean cultivar as affected by row arrangements at Bagauda, Nigeria, rainy season 1990.[1]

Treatment	Sorghum[2] Grain yield (t ha^{-1})	Sorghum[2] LER[3]	Soybean[2] Grain yield (t ha^{-1})	Soybean[2] LER	Total LER
Cultivar					
ICSV 247	1.38	0.42	0.60	0.59	1.01
ICSH 507	1.67	0.49	0.54	0.52	1.01
Samsorg 14	0.97	0.94	0.33	0.32	1.26
SE	±0.091		±0.024		
Row arrangement					
Alternate rows					
1S/1 Soy	1.12	0.48	0.49	0.48	0.96
1S/2 Soy	1.63	0.68	0.42	0.41	1.09
Alternate stand					
1S/1 Soy	1.27	0.52	0.55	0.54	1.06
SE	±0.091		±0.024		
CV (%)	21		15		

1. Randomized block design with 3 replications, net plot size = 18 m^2
2. Sole crop yields: a) sorghum: ICSV 247 = 3.24 t ha^{-1}; ICSH 507 = 3.39 t ha^{-1}; Samsorg 14 = 0.40 t ha^{-1}.
   b) soybean: TG × 1497-1 D = 1.02 t ha^{-1}.
3. LER = Land equivalent ratio calculated using intercrop yield divided by sole crop yield.

We evaluated the sorghum/pigeonpea intercrop system using three sorghum cultivars (S) ICSV 247, ICSH 507, and Samsorg 14, and three pigeonpea cultivars (P): ICPL 84023 (extra-early), ICPL 151 (early), and ICPL 87067 (medium) in a 1S:1P row arrangement. Samsorg 14 and ICPL 87067 did not produce any grain due to drought. The individual LERs of sorghum cultivars were higher than the expected LER of 0.5, whereas pigeonpea LERs were very low (<0.5), indicating a yield depression of pigeonpea in the intercrop (Table 5). This yield reduction was probably due to drought stress and insect damage. The system gave no yield advantage, as indicated by a total LER of less than 1.0.

We conducted another preliminary trial to determine the effect of row arrangement on the system. Two sorghum (S) cultivars, ICSV 247 and Samsorg 14 and two pigeonpea (P) cultivars, ICPL 87 (Early) and ICPL 87067 (Medium) were sown in two-row arrangements, 1S/1P and 2S/1P on 7 July 1990. Samsorg 14 and ICPL 87067 failed to produce grains because of drought. A 14% yield advantage was obtained with the 2S/1P row arrangement but only 7% with the 1S/1P (Table 6). Sorghum produced grain yields of 3.37 in 2S/1P and 2.52 t ha^{-1} in 1S/1P. In both cases, pigeonpea grain yields were very low because of drought stress and insect damage. However, the fodder and fuel components of the crop would compensate for the poor grain yields thus contributing to the overall productivity of the system.

Table 5. Grain yield of two sorghum and two pigeonpea cultivars in sole and intercrops at Bagauda, Nigeria, rainy season 1990.[1]

	Sorghum			Pigeonpea		
Cultivar	Grain yield (t ha^{-1})	LER[2]	Cultivar	Grain yield (t ha^{-1})	LER	Combined LER
ICSV 247 - Sole	2.43	-	ICPL 84023 - Sole	0.68	-	
ICSV 247/ICPL 84023	1.37	0.56	ICPL 84023/ICSV 247	0.14	0.21	0.77
ICSV 247/ICPL 151	1.32	0.54	ICPL 151/ICSV 247	0.01	0.03	0.57
ICSH 507 - Sole	2.18	-	ICPL 151-Sole	0.38	-	-
ICSH 507/ICPL 84023	1.44	0.66	ICPL 84023/ICSH 507	0.05	0.07	0.73
ICSH 507/ICPL 151	1.13	0.52	ICPL 151/ICSH 507	0.03	0.08	0.60
SE	±0.281		SE	±0.023		
Mean	1.65		Mean	0.21		
CV (%)	29		CV (%)	18		

1. Randomized block design with 3 replications, net plot size = 15 m^2.
2. LER = Land equivalent ratio, calculated as intercrop yield divided by sole crop yield.

Table 6. The effect of row arrangement on the grain yields of sorghum (S) and pigeonpea (P) cultivars, Bagauda, Nigeria, rainy season 1990.[1]

	Sorghum[2]		Pigeonpea[2]		
Treatment	Grain yield (t ha^{-1})	LER[3]	Grain yield (t ha^{-1})	LER	Total LER
Row arrangement					
1S/1P	2.52	0.57	0.08	0.50	1.07
2S/1P	3.37	0.77	0.06	0.37	1.14
SE	±0.278		±0.023		
CV (%)	14		39		

1. Randomized block design with 3 replications, net plot size = 27 m^2
2. Sole crop yields: sorghum (ICSV 247) = 4.38 t ha^{-1}, pigeonpea (ICPL 87) = 0.16 t ha^{-1}.
3. LER = Land equivalent ratio calculated using intercrop yield divided by sole crop yield.

Sorghum/Millet/Cowpea

Sorghum/millet/cowpea intercropping is one of the most common multiple cropping systems practiced by peasant farmers in the low to intermediate rainfall areas (500 - 900 mm). This system offers the farmer flexibility in time of sowing the different crops as the cropping season progresses. Furthermore, the system reduces the risk of total crop failure. However, the productivity of the system is often low due to many factors including cultivars, and the spatial and temporal arrangement of the crops.

In collaboration with IITA, we initiated a preliminary trial to evaluate the system using two sorghum (S) cultivars, ICSV 247 (early, medium height) and Samsorg 14 (late, tall); two millet (M) cultivars, Ex-Borno (early, medium height) and Maiwa (late, tall) and two cowpea (C) cultivars, IT 2246 (early, erect) and Kannanado (late, spreading). Sorghum and millet cultivars were sown on 11 July 1990, in alternate rows (1S/1M); cowpea was sown 2 weeks later, on 23 July, between the millet stands.

Table 7 shows the grain yield data. ICSV 247 yielded more than Samsorg 14 in the intercrop, but in either case grain yields did not significantly differ among the different associations. The grain yield of Ex-Borno appeared to be more adversely affected by IT 2246 than by Kannanado. Maiwa had higher grain yield than Ex-Borno in all the combinations. However, grain yields of both millet cultivars were poor, mainly due to insect damage. IT 2246 was more adversely affected in the intercrop than Kannanado. Kannanado, a spreading variety was able to intercept more radiation between the rows of sorghum and millet whereas IT 2246, an erect variety, was shaded by the millet. Competition for nutrients and water is also greater among cultivars of similar maturity. As a whole, the system was adversely affected by drought. In future trials, we will investigate the effects of spatial and temporal arrangement and nutrient levels on the performance of the system.

Table 7. Grain yield of two sorghum, two pearl millet, and two cowpea cultivars grown as intercrops at Bagauda, Nigeria, rainy season 1990.[1]

	Sorghum[3]	Pearl Millet[3]	Cowpea[3]
Cultivar[2]	Grain yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)	Grain yield ($t\ ha^{-1}$)
ICSV 247/Ex-Borno/IT 2246	1.37	0.11	0.05
ICSV 247/Ex-Borno/Kannanado	1.36	0.17	0.07
ICSV 247/Maiwa/IT 2246	1.58	0.22	0.04
ICSV 247/Maiwa/Kannanado	1.30	0.46	0.17
Samsorg 14/Ex-Borno/IT 2246	1.16	0.12	0.05
Samsorg 14/Ex-Borno/Kannanado	0.93	0.13	0.04
Samsorg 14/Maiwa/IT 2246	0.82	0.32	0.03
Samsorg 14/Maiwa/Kannanado	0.97	0.23	0.04
SE	±0.157	±0.013	±0.005
CV (%)	23	10	15

1. Randomized block design with 3 replications, net plot size = 18 m^2.
2. Sorghum = ICSV 247 and Samsorg 14, Pearl millet = Ex-Borno and Maiwa, Cowpea = IT2246 and Kannanado.
3. Sole crops: a) sorghum: ICSV 247 = 4.64 $t\ ha^{-1}$; Samsorg 14 = 1.87 $t\ ha^{-1}$.
   b) millet: Ex-Borno = 0.08 $t\ ha^{-1}$ Maiwa = 0.12 $t\ ha^{-1}$.
   c) cowpea: IT 2246 = 1.23 $t\ ha^{-1}$ Kannanado = 0.14 ha^{-1}.

Biotic Stresses

Insect Pests

Shoot Fly

The 1988 and 1989 International Shoot Fly Nurseries (ISSFN), each consisting of 25 entries, including Farafara as the local control and CSH 1 as the susceptible control, were sown at Bagauda 4 weeks later than crops in nearby fields. In the 1988 nursery, main-shoot deadhearts ranged from 0 to 9.3%, with CSH 1 scoring the highest and Farafara, the local control, scoring 0. Shoot fly deadhearts in tillers ranged from 0 to 16%, with IS 24357 scoring the highest. The differences were not significant.

In the 1989 nursery, main-shoot deadhearts ranged rom 0 to 8.3%, with IS 24361 scoring the highest; Farafara had 1.3%, while CSH 1 had 5.3% deadhearts. Tiller deadhearts ranged from 0 to 21.7%, with CSH 1 having the highest score and Farafara scoring 2.5%. The differences were not statistically significant.

Stem Borers

The 1988 and 1989 International Sorghum Stem Borer Nurseries (ISSBN), including Farafara and CSH 1 as the local and susceptible controls, respectively, were sown at Bagauda in 1990. As in 1989, stem borer incidence at Bagauda, as measured by percentage of plants showing deadhearts per plot at 4 weeks after emergence, was low: 0-3% in ISSBN 1988 and 0-8% in ISSBN 1989.

A survey of stem borer incidence on sorghum in farmers' fields was conducted in Kano and Katsina states (Sudan Savanna Zone) and in Kaduna and Sokoto states (Northern Guinean Savanna Zone). We examined a total of 12 400 plants at 64 locations in August 1990. Percentage of plants showing leaf-feeding by stem borer ranged from 1 in Gumel (extreme northern limit of Northern Sudan Savanna) to 90 near Zaria in the Northern Guinean Savanna. There was a progressive increase in stem borer incidence from the Northern Sudan Savanna to the Northern Guinean Savanna Zones. Of the 222 stem borer larvae collected during the survey and reared in the laboratory at Kadawa, 92.5% were *Busseola fusca* Fuller. Others were *Sesamia* spp and *Coniesta ignefusalis* Hampson. Of the 500 adults that emerged from larvae/pupae collected at Bagauda and Kadawa (Sudan Savanna), 63% were *B. fusca*, 30% *Sesamia* spp, 1% *Coniesta ignefusalis*, and 6% unidentified.

An attempt was made to quantify levels of stem borer damage in farmers' fields by comparing grain yields in sprayed and unsprayed portions of sorghum farms at 17 locations. Spraying with dimethoate increased grain yield twofold. However, this increase was partly due to control of the spittle bugs, *Locris rubra* and *Poophilus maculatus*, which were found on 22-75% of the sorghum plants during the survey.

Sorghum Midge

The 26 entries in the 1989 International Sorghum Midge Nursery (ISMN) were again sown in 1990 at Bagauda. Infestation was higher (24 to 149 infested florets per 500 florets) in 1990 than in 1989, with the local control (Farafara) showing 60 infested florets and ICSV 197 showing 59. The differences were not significant.

Among 32 entries contributed by WASIP/Mali, midge infestation ranged from 32 to 106 per 500 florets; In Farafara (local control) there were 32 infested florets per 500. Differences were not significant.

Head Bugs

Six trials were conducted on head bugs at Bagauda during the 1990 rainy season.

International Sorghum Head Bug Nursery (ISHBN). The 18 entries in the 1989 ISHBN which showed moderate resistance to *Calocoris angustatus* in India were sown with a local (Farafara) and a susceptible control. Head bug numbers per 5 panicles at dough stage ranged from 5 in IS 17645 to 66 in IS 27397. Six entries had 5-10 bugs (Table 8); of these, IS 20740 and IS 17610 had given similar performance in 1989 (ICRISAT West African Programs Annual Report 1989, p. 113, Table 6).

Head Bug Resistant Varieties (HBRV). Thirty-two lines found resistant to *C. angustatus* were again tested under natural infestation by *Eurystylus* at Bagauda, with Nagawhite as the local (Ghanaian) control variety. Head bug populations per 5 panicles at dough stage ranged from 3 in IS 17645 to 30 in IS 13560. Six entries had fewer than 5 bugs; 13 others had fewer than 10 bugs (Table 9). Of these 19 entries, IS 21443, A 7081, IS 17645, and IS 21525 also had fewer than 10 bugs in 1989 (ICRISAT West African Programs Annual Report, p. 113, Table 7).

These 32 entries were artificially infested in headcages with 10 pairs of *Eurystylus* third-instar nymphs at the dough stage. Head bug populations on 2 panicles 20 days after infestation ranged from 34 in Nagawhite to 271 in IS 16123. Only Nagawhite and IS 17645 had fewer than 50 bugs; 14 others had fewer than 100 bugs (Table 10). Eleven of these 16 entries also performed well under natural infestation (Table 9).

Advanced Head Bug Nursery (AHBN). As in 1989, 12 lines were evaluated for infestation by *Eurystylus*, using Nagawhite as a local control. The number of head bugs per 5 panicles ranged from 5 in ICSV 2 to 90 in ICSV 16-5 BF (Table 11). Only ICSV 2 and Malisor 84-1 had fewer than 10 bugs. Head bug counts in this trial were generally higher in 1990 than in 1989.

Table 8. Head bug (*Eurystylus* sp) incidence on selected sorghum cultivars, International Sorghum Head Bug Nursery, Bagauda, Nigeria, rainy season 1990.[1]

Cultivar	Head bug no.[2]
IS 17645	5.0 (2.12)[3]
IS 21443	7.0 (2.64)
IS 15357	8.0 (2.67)
IS 17610	8.5 (2.89)
IS 20740	9.5 (3.08)
IS 21444	9.5 (3.08)
Local control	
Farafara	27.5 (5.23)
SE	(±0.508)
Trial mean (21 entries)	18.02 (3.98)
CV (%)	(18)

1. Randomized complete block design with 2 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

Table 9. Head bug (*Eurystylus* sp) incidence on selected sorghum genotypes at Bagauda, Nigeria, rainy season 1990 (natural infestation).[1]

Cultivar	Head bug no.[2]
IS 17645	3.0 (1.71)[3]
IS 20740	3.3 (1.73)
IS 20638	4.0 (1.88)
IS 8064	4.3 (2.07)
IS 27798	4.7 (2.09)
IS 14108	4.7 (3.72)
IS 22289	5.7 (2.37)
IS 20664	6.0 (2.45)
IS 14317	6.0 (2.40)
IS 21443	6.7 (2.35)
IS 14334	7.0 (2.60)
IS 21468	7.3 (2.63)
IS 21525	7.7 (2.75)
IS 22284	8.0 (2.73)
A 7081	8.7 (2.90)
IS 27332	8.7 (2.78)
IS 27452	9.3 (3.04)
Local control	
Nagawhite	8.0 (2.73)
SE	(±0.474)
Trial mean (32 entries)	10.3 (3.05)
CV (%)	(27)

1. Randomized complete block design with 3 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

Table 10. Head bug (*Eurystylus* sp) incidence on selected sorghum genotypes at Bagauda, Nigeria, rainy season 1990 (artificial infestation) [1]

Cultivar	Head bug no.[2]
IS 17465	44.3 (6.65)[3]
IS 14317	47.3 (6.87)
IS 20740	51.7 (7.18)
IS 20638	57.7 (7.55)
IS 21525	59.7 (7.71)
IS 14334	66 0 (8.09)
IS 27798	66.7 (8.12)
IS 23748	66.7 (8.15)
A 2821	67.3 (8.09)
IS 20664	60.0 (8.16)
IS 27466	71.0 (8.38)
IS 21444	72.3 (8.46)
IS 22289	90.6 (9.26)
IS 19455	97.7 (9.74)
IS 21443	97.7 (9.74)
Local control	
Nagawhite	34.0 (5.77)
SE	(±1.616)
Trial mean (32 entries)	116.7 (0.19)
CV (%)	(28)

1. Randomized complete block design with 3 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

Table 11. Head bug (*Eurystylus* sp) incidence on sorghum cultivars from WASIP/Mali Advanced Head Bug Nursery at Bagauda, Nigeria, rainy season 1990.[1]

Cultivar	Head bug no.[2]
ICSV 2	5.3 (2.24)[3]
Malisor 84-7	7.7 (2.72)
ICSV 1122	15.3 (3.78)
CSM 388	16.7 (4.06)
Gadiaba	18.0 (4.19)
CSM 63	21.7 (4.57)
S 34	22.7 (4.75)
ICSV 1063	36.3 (5.92)
ICSV 1143	48.7 (6.97)
Framida	65.0 (7.85)
ICSV 16-5 BF	93.0 (9.44)
Local control	
Nagawhite	21.3 (4.54)
SE	(±0.545)
Trial mean	30.2 (5.02)
CV (%)	(19)

1. Randomized complete block design with 3 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

Mali Head Bug Nursery (MHBN). Of the 82 lines from WASIP/Mali evaluated in 1989, 78 were again evaluated for *Eurystylus* infestation at Bagauda in 1990, using Nagawhite as the local control. Heag bug populations per 5 panicles at the dough stage ranged from 4 (in 87 W 810) to 52 (in 87 W 742). Eleven entries had fewer than 10 bugs (Table 12).

Table 12. Head bug (*Eurystylus* sp) incidence on selected sorghum lines from WASIP/Mali at Bagauda, Nigeria, rainy season 1990.[1]

Cultivar	Head bug no.[2]
87W 810	4.0 (1.93)[3]
87W 783	5.5 (2.21)
87W 821	6.0 (2.29)
87W 795	6.5 (2.55)
87W 1021	6.5 (2.50)
87W 772	7.5 (2.70)
87W 738	8.0 (2.78)
87W 755	9.0 (3.00)
87W 769	9.0 (2.87)
87W 736	9.0 (2.99)
87W 809	9.5 (2.94)
Local controls	
Nagawhite	17.0 (4.10)
Farafara	54.0 (7.28)
SE	(±0.773)
Trial mean (78 entries)	18.2 (4.06)
CV (%)	(27.2)

1. Randomized complete block design with 2 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

Effect of cypermethrin on head bug incidence. The preliminary trial conducted in 1989 to estimate the avoidable losses due to head bugs was repeated in 1990. Cypermethrin (EC) was sprayed three times at weekly intervals, using four concentrations to create different levels of head bug infestation (Table 13). Head bug populations were estimated on five randomly selected panicles 24 h before and after spraying. As in 1989, the best control was obtained with cypermethrin at 0.02% level. Grain yield and grain mass were increased by 20% and 6%, and floaters were reduced by 24% with the 0.02% cypermethrin spray.

International pest-resistant varieties. Twenty-four entries, a combination of sorghum lines with resistance to shoot fly, stem borer, grain midge, and head bug were evaluated in 1990 for *Eurystylus* infestation. Farafara was used as a local control. The number of bugs per 5 panicles at dough stage ranged from 5.3 in ICSV 705 to 112.7 in ICSV 835. Only three entries—ICSV 714, ICSV 445, and ICSV 705—had fewer than 10 bugs (Table 14).

Spittle Bug Outbreak

There was an unprecedented outbreak of spittle bug infestation on sorghum in Nigeria in 1990. Our surveys revealed that infestation was widespread over northern Nigeria (Sokoto, Katsina, Kano, Bauchi, Borno, Gongola, Benue, Nigeria, Plateau, and Kaduna states). Two spittle bug species were identified: *Poophilus maculatus*, a grey bug, predominated and was associated with most of the leaf damage; *Locris rubra* which was reddish, was less abundant. Infestation ranged from 22 to 100% of plants in farmers' fields and was invariably accompanied by yellowish

Table 13. Effect of cypermethrin on head bug (*Eurystylus* sp) numbers on sorghum (ICSV 247) at Bagauda, Nigeria, rainy season 1990[1].

Cypermethrin concentration (%)	Head bug no.[2] Before first spray	After first spray	After second spray	After third spray	Grain yield (t ha^{-1})	1000-grain mass (g)	Floaters (%)
0.001	1.3 (0.67)[3]	0.7 (0.67)	4.7 (2.10)	3.3 (1.48)	2.1	13.6	87.0 (9.32)
0.005	0 (0)	1.0 (0.80)	1.7 (1.05)	2.0 (1.15)	2.1	13.6	90.0 (9.49)
0.01	0.7 (0.47)	0 (0)	1.3 (0.94)	1.0 (0.58)	2.2	14.0	77.0 (8.77)
0.02	1.0 (0.80)	0 (0)	0.7 (0.67)	0 (0)	2.3	14.1	69.3 (8.33)
Nontreated control	1.0 (0.58)	4.0 (1.99)	9.3 (2.97)	15.3 (3.81)	1.9	13.4	93.0 (9.64)
SE	(±0.525)	(±0.254)	(±0.474)	(±0.480)	±0.21	±0.85	(±0.136)
Mean	0.8 (0.50)	1.1 (0.69)	3.5 (1.54)	4.3 (1.40)	2.1	13.7	83.3 (9.11)
CV (%)	(181)	(64)	(53)	(59)	17	11	(3)

1. Randomized complete block design with 4 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

Table 14. Head bug (*Eurystylus* sp) incidence on selected sorghum cultivars in the International Pest Resistance Nursery, Bagauda, Nigeria, rainy season 1990.[1]

Cultivar	Head bug no.[2]
ICSV 705	5.3 (2.13)[3]
ICSV 445	7.7 (2.19)
ICS 714	8.0 (2.76)
ICSV 680	10.7 (3.23)
ICSV 745	12.7 (3.52)
ICSV 707	13.3 (3.61)
ICSV 700	19.0 (4.11)
Local control	
Farafara	59.0 (7.65)
SE	(±1.356)
Trial mean (24 entries)	36.1 (5.30)
CV (%)	(44)

1. Randomized complete block design with 3 replications.
2. Counted per 5 randomly selected panicles.
3. Figures in parentheses are square root transformed values.

blotches on the leaves which later dried up. These blotches resembled the yellow leaf blotch reported as being caused by bacteria, *Pseudomonas* spp, but there was no doubt that the blotches we found during the surveys were caused by the feeding of the spittle bugs. In some cases, up to 100 nymphs per plant were observed and their feeding by sucking out the plant sap invariably killed young plants and caused the leaves of older plants to dry up completely Such severe infestation resulted in poor exsertion of the panicles and therefore very low grain yields.

All the entries in the ISSFN, ISSBN, ISHBN, HBRV, AHBN, and MHBN were evaluated for spittle bug infestation but none was free of infestation and varietal differences were not obvious. This is a potentially serious insect problem.

Crop Improvement

Our efforts to breed for superior early-maturing cultivars were intensified during 1990, through the evaluation of a large number of newly bred hybrids and varieties in replicated yield trials. Five new male-sterile lines and several early-maturing germplasm accessions were identified for further seed multiplication and distribution in the region. Useful selections were also made from F_2 populations originating from diverse crosses. Our cooperation with seed-producing agencies continued successfully.

Hybrids

We tested eighteen advanced hybrids in a replicated yield trial using two early maturing variety controls. ICSH 89001 NG and ICSH 89002 NG yielded 6.26 (+0.324, CV = 12%) and 5.74 t/ha^{-1} respectively, while the variety controls, ICSV 111 and Samsorg 3 yielded 4.83 and 3.68 t/ha^{-1} respectively (Table 15). ICSH 507, which ranked high in 1988 and 1989 tests yielded 5.41 t/ha^{-1}. Post-floral drought led to severe lodging of the hybrids. Among others, ICSH 89002 NG and ICSH 89013 NG exhibited relatively low lodging scores and higher grain yields. Experimental seed production of ICSH 89002 NG gave promising results.

The IAR (Samaru, Nigeria) and ICRISAT/WASIP (Kano) jointly conducted agronomic trials on ICSH 507 and ICSH 89002 NG at three locations. A Nigerian seed company, Agricultural Seeds Ltd., Zaria, produced seeds of two hybrids, ICSH 507 and ICSH 89001 NG, and their parents on an experimental basis.

Table 15. Grain yield performance of selected advanced sorghum hybrids, Bagauda, Rainy season, 1990.[1]

Cultivar	Time to 50% flowering (d)	Plant height (cm)	Grain yield (t ha-^{1})	Lodging[2]	1000-grain mass (g)	Floaters[3] (%)
ICSH 89001 NG	61	220	6.26	4.3	22.8	74
ICSH 89014 NG	62	223	6.25	3.3	26.1	66
ICSH 89008 NG	62	197	5.80	3.7	23.0	78
ICSH 89002 NG	67	215	5.74	3.0	23.3	77
ICSH 89013 NG	67	218	5.45	1.7	21.8	83
ICSH 507	61	193	5.41	5.0	19.5	72
ICSH 89005 NG	68	197	4.78	3.0	21.2	61
INRAN Sorghum Hybrid 1	67	200	5.04	3.0	22.7	65
Variety controls						
ICSV 111	63	222	4.83	2.7	27.6	63
Samsorg 3	63	188	3.68	4.0	23.3	91
SE	±0.5	±5.3	±0.324	±0.82	±1.07	±5.5
Trial mean (20 entries)	64	202	5.20	3.1	22.1	74
CV (%)	2	5	12	46	8	13

1. RBD, 3 replications, net plot size 18 m^2
2. Lodging was scored on a scale of 1 to 5 where 1 = 0% lodging and 5 = 100% plants lodged.
3. Percentage of floating grains was observed by placing a sample of 100 grains in a solution of sodium nitrate (1.3 sg).

A large number of early-maturing preliminary hybrids (223), produced using 7 female parents, was tested in 8 replicated yield trials, and 40 of them were chosen for advancement (Tables 16 and 17). Severe terminal drought enabled us to select for stalk lodging resistance which is important for high-yielding hybrids when grown under drought. Promising hybrids yielding more than 5 t ha^{-1} with good grain quality and lodging and disease resistance were identified.

One hundred and sixty test crosses were visually evaluated in an initial observation nursery and ten fertile hybrids were selected for preliminary yield trials.

Five new male-sterile lines (A/B lines) (M 90218A, M 90220A, M 90222A, M 90230A, and M 90254A) were identified from 23 preliminary selections and will be tested for combining ability during the next season.

Table 16. Performance of selected experimental hybrids in various preliminary hybrid trials, Bagauda, rainy season 1990.[1]

Entry	Time to 50% flowering (d)	Plant height (cm)	Grain yield (t ha^{-1})	Lodging score[2]
ICSA 41 × MR 927-1	62	203	7.54	3.7
ICSA 37 × ICSV 112	62	203	7.47	4.0
ICSA 37 × MR 912-2	62	190	7.35	2.7
ICSA 41 × MR 904-2	65	202	7.05	4.0
ICSA 11 × ICSV 259	62	212	6.99	2.0
ICSA 41 × ICSV 242	64	218	6.88	2.7
ICSH 507 (Control)	60	198	6.79	5.0
SE	±0.6	±5.2	±0.457	±0.8
Trial mean (36 entries)	62	196	6.43	3.1
CV (%)	2	5	12	45
ICSA 41 × MR 732	64	192	7.62	3.0
ICSA 38 × MR 732	65	187	6.82	3.7
ICSA 41 × ICSV 361	64	207	6.82	3.0
ICSA 37 × MR 918	64	193	6.81	2.3
ICSA 507 (Control)	63	195	6.68	3.0
ICSA 39 × ICSV 247	65	207	6.59	3.7
ICSH 39 × MR 732	66	193	6.10	3.3
SE	±0.6	±7.2	±0.367	±0.9
Trial mean (36 entries)	65	198	6.31	3.1
CV (%)	2	6	10	50
ICSA 11 × M 24791	62	215	7.17	3.3
ICSA 11 × M 36170	62	203	6.70	3.3
ICSH 507 (Control)	59	197	6.63	5.0
ICSA 11 × MR 877	64	177	5.85	1.7
ICSA 2 × ICSV 361	61	172	5.78	1.3
ICSA 2 × MR 917	61	173	5.58	1.0
SE	±0.6	±7.0	±0.545	±0.60
Trial mean (25 entries)	60	185	5.76	3.1
CV (%)	2	7	16	32

1. 6 × 6 lattice or 5 × 5 lattice experiments with 3 replications; net plot size 12 m^2.
2. Lodging was scored on a scale of 1 to 5; where 1 = 0% lodging, and 5 = 100% plants lodged.

Table 17. Performance of selected experimental hybrids in various preliminary hybrid trials, Bagauda, rainy season 1990.[1]

Entry	Time to 50% flowering (d)	Plant height (cm)	Grain yield (t ha^{-1})	Lodging score[2]
ICSA 37 × MR 860	65	210	6.40	2.7
ICSH 507 (Control)	61	203	6.17	4.3
ICSA 37 × MR 861	67	190	5.84	1.3
ICSA 37 × MR 871	63	188	5.78	1.7
ICSA 37 × M 60328	68	213	5.49	2.0
ICSA 37 × M 24525	65	208	5.19	2.0
SE	±0.7	±5.6	±0.367	±0.7
Trial mean (25 entries)	66	195	5.19	2.8
CV (%)	2	5	12	45
ICSA 38 × M 24525	65	203	5.84	2.3
ICSA 38 × ICSV 400-2	65	203	5.70	3.3
ICSA 38 × MR 801	64	188	5.66	3.7
ICSH 507 (Control)	61	180	4.88	4.0
SE	±0.6	±8.0	±0.540	±0.58
Trial mean (25 entries)	65	189	4.40	3.61
CV (%)	2	7	21	28
ICSA 39 × MR 927-2	65	197	6.22	4.7
ICSA 39 × MR 918	65	193	6.17	3.7
ICSA 39 × M 24791	68	203	5.81	2.3
ICSH 507 (Control)	63	198	5.30	4.7
ICSA 39 × MR 849	73	212	4.52	1.7
SE	±0.5	±4.9	±0.421	±0.6
Trial mean (25 entries)	67	193	4.90	3.8
CV (%)	1	4	15	27
ICSA 41 × MR 861	64	190	6.02	2.7
ICSA 41 × MR 817	62	187	5.92	3.3
ICSA 41 × Suc 36	64	160	5.53	2.7
ICSH 507 (Control)	62	188	5.46	5.0
ICSA 41 × MR 944-2	62	192	5.28	4.0
ICSA 41 × M 24525	65	197	5.19	3.3
ICSA 41 × M 36170	67	193	5.17	2.0
SE	±0.55	±9.2	±0.539	±0.75
Trial mean (25 entries)	64	189	5.04	3.8
CV (%)	2	9	19	34

1. 5 × 5 lattice experiments with 3 replications; net plot size 12 m^2.
2. Lodging was scored on a scale of 1 to 5; where 1 = 0% lodging, and 5 = 100% plants lodged.

Varieties

Seventeen early-maturing advanced varieties were tested in replicated trials using 18 m^2 plots. ICRISAT varieties, ICSV 111 and ICSV 400, yielded 5.13 and 4.81 t ha^{-1} respectively (SE ±0.526; CV 12%) while the control varieties Gaya Early and Samsorg 14 yielded 3.91 and 2.09 t ha^{-1} respectively (Table 18).

Table 18. Grain yield performance of advanced sorghum varieties, Bagauda, Rainy season, 1990[1]

Cultivar	Time to 50% flowering (d)	Plant height (cm)	Grain yield (t ha^{-1})	Lodging[2]	GLS[3]	1000-grain mass (g)	Floaters[4] (%)
Nagawhite	63	213	5.96	3.0	3.3	25.1	100
ICSV 111	63	218	5.13	3.0	2.7	27.5	62
ICSV 400	66	210	4.81	1.3	2.3	27.2	73
ICSV 401	65	203	4.75	2.7	3.0	24.6	66
White mutant of Framida	66	215	4.59	1.7	3.0	26.7	96
ICSV 210	66	225	4.53	3.0	2.3	20.0	47
Samsorg 3 (Control)	63	187	4.49	2.7	2.7	23.8	95
ICSV 247	67	197	4.47	1.7	2.7	20.3	53
Gaya Early (Control)	76	342	3.92	1.7	2.0	27.6	99
Samsorg 14 (Control)	86	343	2.09	1.3	2.0	31.1	100
SE	±3	±5.3	±0.526	±0.39	±0.25	±0.94	±7.9
Trial mean (20 entries)	68	221	4.30	2.0	2.4	22.9	67
CV (%)	8	4	12	33	18	7	20

1. RBD, 3 replications, net plot size 18 m^2
2. Lodging was scored on a scale of 1 to 5 where 1 = 0% lodging and 5 = 100% plants lodged.
3. GLS = grey leaf spot disease, scored on a scale of 1 to 5; where 1 = less than 5% leaf area infected, and 5 = more than 50% leaf area infected.
4. Percentage of floating grains determined by placing a sample of 100 grains in a solution of sodium nitrate (1.3 sg).

ICSV 400 is an early-maturing (105-110 days), medium-tall (2 m) variety with good grain quality and resistance to lodging. Grain samples of this variety were tested several times by a local brewery in Nigeria and found to possess superior malting and brewing qualities.

ICSV 111 is being multiplied and distributed by the Crops Research Institute, Nyankpala, in the northern region of Ghana. Eighty preliminary varieties were tested in 3 replicated yield trials and 31 of them were selected for advanced variety trials. Some of these selections were derived from a stable high-yielding and adapted brown-grain cultivar, Nagawhite, and yielded on par with the control, ICSV 400 (Table 19).

Sixty-six early-maturing germplasm selections (46-70 days to flower) were tested in replicated yield trials, and some 30 lines exhibiting useful agronomic characters and high yield (2.5 t ha^{-1}) were selected for seed multiplication and distribution in the region (Table 20).

Several segregating populations (85) were evaluated in the F_2 generation, and 222 individual selections from 25 populations were selected for pedigree evaluation. The parents of these crosses had disease resistance, local adaptation, good grain quality, and high yield.

Table 19. Grain yield performance of selected preliminary sorghum varieties, Bagauda, rainy season 1990[1].

Entry	Time to 50% flowering (d)	Plant height (cm)	Grain yield (t ha^{-1})
(83SB Pop Keninke 4-11-1 × M24667)-1-3-4	71	208	6.24
(M60264 × Nagawhite)-2-1-1	67	217	6.17
(M60264 × Nagawhite)-1-2-5	69	192	6.10
(M60264 × Nagawhite)-1-2-4	72	215	5.98
(M60264 × Nagawhite)-1-2-3	72	218	5.68
(S-34 × ICSV 1002 BF)-3-3-1	73	157	5.61
(M60264 × Nagawhite)-1-2-1	69	212	5.42
(S-34 × ICSV 1002 BF)-8-1-1	72	225	5.32
Controls			
ICSV 247	64	190	5.18
Samsorg 3	63	178	4.99
SE	±1.0	±8.4	±0.589
Trial mean (36 entries)	70	197	4.914
CV (%)	3	7	21

1. 6 × 6 lattice, 3 replications; net plot size 12 m^2.

Cooperation with National Programs

The second in the series of meetings between WASIP/Nigeria and sorghum scientists in eight West African countries was held in Kano 11-12 Sep 1990.

A cooperative project, "Screening for malting quality in sorghum," with the Department of Food Technology, University of Ibadan, was started. Cooperation with several breweries in Nigeria continued. We are also cooperating with the Scottish Crop Research Institute, UK, in developing efficient sorghum malting quality evaluation techniques.

Seeds of elite hybrids (ICSH 507 and ICSH 89002 NG) and varieties (ICSV 111, ICSV 400, ICSV 247, and ICSV 401) were supplied in bulk quantities to National Seed Service, Nigeria, and other interested national programs in the region such as Mali, Burkina Faso, Côte d'Ivoire, and Niger.

A short training course in sorghum hybrid seed production techniques was conducted during early September 1990 (for the second successive year) for 12 Nigerians drawn from national research institutes, private and public sector undertakings, and the National Seed Service. Agricultural Seeds Ltd., a seed company in Zaria, was assisted in experimenting with sorghum hybrid seed production. Seeds of our elite hybrids and their parents were also supplied to them.

A regional hybrid trial, West African Sorghum Hybrid Adaptation Trial, 1990, was organized under the auspices of the WCASRN at 12 locations in the region.

Seeds of four early-maturing varieties and four hybrids were contributed to the state trials conducted by the IAR in the northern region of Nigeria. The IAR was also assisted in conducting these trials. Seeds of improved varieties were supplied to two large-scale private farmers in Nigeria. Agronomic and entomological trials were conducted jointly with IAR, Samaru, while physiological and agronomic studies were jointly executed with the Lake Chad Research Institute (LCRI), Maiduguri, on dry-season (*Moskwari*) sorghum grown on Vertisols. Collaborative agronomic trials on multiple-cropping systems were also run jointly with IITA.

Cooperative sorghum nurseries were evaluated at Station Tarna, Maradi, Niger, in collaboration with INRAN scientists and useful observations were made.

Seeds of three early-maturing varieties, four medium- maturing varieties, and a hybrid were contributed to the multilocational trials conducted by IRA, Maroua, Cameroon.

Table 20. Grain yield performance of selected early-maturing sorghum germplasm accessions, Bagauda, rainy season 1990[1].

Accession	Origin	Time to 50% flowering (d)	Plant color[2]	Plant height (cm)	Grain color[3]	Grain yield (t ha^{-1})
IS 10566	USA	57	P	113	W	3.12
IS 2233	USA	55	T	110	W	2.92
IS 517	Mexico	58	T	115	W	2.82
IS 3026	Ethiopia	57	P	115	R	2.61
IS 2229	USA	57	T	97	W	2.58
IS 3796	USA	58	P	122	Y	2.57
IS 10370	Israel	56	T	108	W	2.54
IS 174	USA	55	T	133	W	2.52
IS 2385	South Africa	58	P	130	R	2.48
IS 2021	USA	57	T	132	W	2.46
IS 3935	USA	56	T	113	Y	2.43
IS 2954	South Africa	58	P	137	Y	2.40
IS 225	USA	60	P	113	W	2.31
IS 10252	USA	59	P	108	W	2.28
IS 153	USA	56	P	117	W	2.28
IS 9302	South Africa	56	P	167	R	2.26
IS 888	USA	46	T	130	W	2.10
Controls						
Gaya Early	Nigeria	76	P	220	W	1.39
Samsorg 3	Nigeria	63	T	157	W	1.33
SE		±0.6		±6.8		±0.295
Trial mean (36 entries)		59		139		2.05
CV (%)		2		9		25
IS 14326	Botswana	59	P	192	W	3.56
IS 19437	Burkina Faso (S-13)	59	T	130	W	3.45
IS 19454	Botswana	59	P	173	W	3.39
IS 13837	South Africa	60	P	158	R	3.23
IS 19552	Sudan	59	T	122	W	3.22
IS 19234	Sudan	59	P	148	W	3.14
IS 18731	USA	66	P	110	W	3.00
IS 21800	Sudan	59	P	140	Y	2.98
IS 20501	Sudan	61	T	142	W	2.87
IS 21458	Malawi	61	P	257	W	2.84
IS 21749	Sudan	57	T	133	W	2.80
IS 13904	South Africa	63	P	167	R	2.71
IS 19535	Sudan	62	P	112	W	2.58
IS 18734	USA	63	P	110	W	2.54
IS 18749	USA	63	P	122	W	2.50
IS 18410	India	63	T	252	W	2.42
Control						
Samsorg 14	Nigeria	82	P	263	W	0.44
SE		±0.8		±6.8		±0.256
Trial mean (36 entries)		63		159		2.48
CV (%)		2		7		18

1. 6 × 6 lattice, 3 replications, plot size 12 m^2.
2. Plant color: P = purple T = tan.
3. Grain color: W = White R = red Y = yellow.

ICRISAT/MALI Bilateral Program

Introduction

During 1990, ICRISAT's final year of national program research support activities in Mali, we initiated the process of handing over to Malian scientists the technical responsibility for carrying out sorghum breeding and cropping systems research. The ICRISAT plant breeder left Mali during the year and a Malian sorghum breeder took over the responsibility of maintaining the breeding materials and testing advanced cultivars. The agronomy program focused on confirming the results already obtained in the cropping systems research. No new research projects were begun. The Malian national agronomists were encouraged to take complete responsibility for cropping systems research and to undertake research on soil fertility problems related to sorghum-and millet-based systems.

A terminal report, summarizing the activities and achievements of the ICRISAT-Mali Bilateral Program during its 12 years was written and is being printed at ICRISAT Center.

During the year, a modest program on cropping systems research was continued to refine the systems earlier developed. Millet/maize, cereal/groundnut, and cereal/cowpea systems were further evaluated by Malian research and extension personnel under farmers' conditions. Studies to develop packages of technology for improved cereal cultivars developed by our breeders were continued in cooperation with the Malian agronomists.

Though the onset of rains in 1990 was early, the total rainfall throughout Mali was below the long-term mean, and its distribution poor: above normal in July and below normal in August (Table 1).

Table 1. Total rainfall (mm) at Sotuba and Cinzana, Mali, 1990.

Month	Sotuba	Cinzana
April	15.7	2.6
May	58.7	1.0
June	146.8	56.6
July	259.7	237.0
August	188.4	165.2
September	135.2	83.3
October	22.7	27.2
November	0	0
Total, 1990	827.2	583.9
Long-term annual mean	1014	709

Sorghum-based Cropping Systems

We evaluated four sorghum cultivars–two introduced (S 34 and ICSV 1063) and two local (CSM 388 a local improved variety, and Sakoika, a cultivar commonly grown by farmers under two levels each of plant density and fertilizer N. The introduced cultivars flowered earlier, and were shorter and higher yielding than the local cultivars (Table 2). Early-maturing ICSV 1063 was the highest-yielding of all the cultivars evaluated, followed closely by medium-duration S 34. The local cultivars, being susceptible to late-season drought, suffered severe yield losses. Plant density did not affect grain yields significantly, although shorter cultivars ICSV 1063 and S 34 did show an increasing yield trend with increasing plant density. Fertilizer N increased grain yields of all the cultivars.

Table 2. Effect of cultivar, plant population, and fertilizer N on the growth and yield of sorghum, Sotuba, Mali, rainy season 1990.

Treatment	Time to 50% flowering (days)	Plant height (m)	Panicle no.m^{-2}	Grain yield (t ha^{-1})
Cultivar				
S 34	80	1.81	4.2	2.1
ICSV 1063	71	1.92	4.7	2.4
CSM 388	84	3.92	4.9	1.4
Sakoïka	84	3.77	4.4	1.3
SE	±0.47	±0.07	±0.27	±0.11
Crop density (plants m^{-2})				
5	80	2.82	4.1	1.7
10	79	2.89	5.0	1.8
SE	±0.33	±0.05	±0.19	±0.08
N applied (kg ha^{-1})				
0	80	2.83	2.0	1.6
50	79	2.87	2.1	2.0
SE	±0.33	±0.05	±0.19	±0.08
CV (%)	2	9	21	22

In another trial, we examined the performance of individual components of improved technology separately and in combination. We evaluated an improved (S 34) and a local (Sakoika) cultivar under two levels each of tillage and added fertilizer (Table 3). Varietal and added fertilizer effects were observed in 1990 as in previous years. Tied ridging reduced sorghum yield because of water stagnation in this treatment during late July and early August; this effect had also been observed in 1988, a higher rainfall year. As expected, S 34 yielded better than Sakoika, confirming the superiority of the improved cultivar over the local cultivar.

These results indicated that moisture-conservation measures are not critical in the Sudano-Guinean Zone; nutrient and varietal constraints have a greater effect on sorghum yields in the region. Therefore, the Mali research program is now placing more emphasis on soil fertility management and developing fertilizer-responsive sorghum cultivars.

A traditional system of mixed cropping in Mali is to sow sorghum and cowpea in the same pocket. The farmers usually mix sorghum and cowpea seeds and sow them together in hills (pockets). We evaluated the effect of six seeding rates of cowpea and two levels of added fertilizer on the performance of this cropping system and found that increasing cowpea seeding rates increased cowpea grain yields without significantly affecting sorghum growth and grain yields (Table 4). The highest cowpea yield and LER were obtained with the seeding rate of 45 kg ha^{-1} which gave a plant density of about 70 000 to 80 000 plants ha^{-1}, confirming our earlier intercropping (sorghum and cowpea in separate rows) research results on optimum cowpea density. Topdressing N at 23 kg ha^{-1} also increased grain yields of both sorghum and cowpea, resulting in higher LER.

Table 3. Effect of tillage, fertilizer, and cultivar on the growth and yield of sorghum, Sotuba, Mali, rainy season 1990.

Treatment	Time to 50% flowering (days)	Plant height (m)	Panicle no.m^{-2}	Grain yield (t ha^{-1})
Tillage				
Plowing	83	3.24	4.1	1.8
Plowing + tied ridges	86	2.91	4.1	1.5
Fertilizer added (kg ha^{-1})				
N - P_2O_5 - K				
0 - 0 - 0	85	2.92	4.3	1.5
41 - 46 - 0	84	3.23	3.9	1.8
Cultivar				
S 34	82	2.46	4.4	2.1
Sakoïka	87	3.69	3.8	1.2
SE	±0.55	±0.27	±0.11	±0.08
CV (%)	3	36	11	22

Table 4. Influence of cowpea seeding rate and added fertilizer on the performance of sorghum/cowpea mixed cropping (sown in the same pocket), Sotuba, Mali, rainy season 1990.

Treatment	Grain yield (t ha^{-1})		LER[1]		
	Sorghum	Cowpea	Sorghum	Cowpea	Total
Cowpea seeding rate (kg ha^{-1})					
60	1.40	0.24	0.69	0.34	1.03
45	1.30	0.38	0.66	0.53	1.19
30	1.25	0.33	0.63	0.46	1.09
15	1.33	0.20	0.67	0.29	1.09
7.5	1.47	0.12	0.74	0.17	0.91
3.75	1.54	0.12	0.77	0.10	0.87
SE	±0.12	±0.03			
Fertilizer added (kg ha^{-1})					
N - P_2O_5 - K					
18 - 46 - 0	1.30	0.21	0.66	0.30	0.96
41 - 46 - 0	1.45	0.25	0.73	0.36	1.09
SE	±0.07	±0.02			
CV (%)	25	40			

1. LER = Land equivalent ratio.

Millet-based Cropping Systems

We evaluated five millet cultivars–four improved ones developed by the Mali pearl millet breeding program and local cv Boboni as the control– under two levels each of plant density and added fertilizer at our Cinzana research station. Of the improved cultivars, 81 BHT, which is early-maturing and of medium height, performed best but its grain yield was similar to that of the local Boboni. The grain yields of Synth 11, Synth 16, and PN 4 were significantly lower than that of the local control. Increased crop density had no effect on grain yields, mainly because of the good tillering ability of all the cultivars studied. Addition of fertilizer improved the growth and yield of all the cultivars evaluated, with a 40% grain yield increase (Table 5). We did not observe any differential response to added fertilizer among the cultivars studied.

Table 5. Effect of cultivar, plant population, and added fertilizer on the growth and yield of pearl millet, Cinzana, Mali, rainy season 1990.

Treatment	Time to 50% flowering (days)	Plant height (m)	Panicle no.m^{-2}	Grain yield (t ha^{-1})
Cultivar				
Synth 11	66	2.06	6.2	1.1
Synth 16	68	1.23	6.6	0.8
PN 4	68	1.42	6.0	1.0
81 BHT	62	1.44	9.5	1.6
Boboni	67	2.30	7.8	1.5
SE	±0.5	±0.03	±0.36	±0.06
Crop density (plants m^{-2})				
3	66	1.70	7.1	1.2
6	66	1.68	7.4	1.2
SE	±0.3	±0.02	±0.23	±0.04
Fertilizer added (kg ha^{-1})				
N - P_2O_5 - K				
0 - 0 - 0	66	1.65	6.4	0.9
41 - 46 - 0	66	1.73	8.1	1.4
SE	±0.3	±0.02	±0.23	±0.04
CV (%)	3	7	20	21

In another trial on improved agronomic pratices, we studied the effect of tillage, added fertilizer, and improved variety at Cinzana Research Station. The improved cultivar M2 D2 yielded significantly more than with local cv Boboni (Table 6). Tillage and fertilizer did not significantly affect millet grain yields; however, the yields showed an increasing trend with added fertilizer, particularly M2 D2. Cv Boboni yielded 1.5 t ha^{-1} with plowing and no added fertilizer but M2 D2 produced about 2 t ha^{-1} of grain yield with added fertilizer, indicating a yield gap of about 25% between the local and improved systems.

Table 6. Effect of tillage, fertilizer, and cultivar on the growth and yield of pearl millet, Cinzana, Mali, rainy season 1990.

Treatment	Time to 50% flowering (days)	Plant height (m)	Grain yield (t ha^{-1})
Tillage			
Plowing	64	2.48	1.66
Plowing + tied ridges	64	2.37	1.59
Fertilizer added (kg ha^{-1})			
N - P_2O_5 - K			
0 - 0 - 0	64	2.43	1.58
41 - 46 - 0	64	2.43	1.67
Cultivar			
Boboni	64	2.48	1.46
M2D2	64	2.37	1.80
SE	±0.52	±0.05	±0.06
CV (%)	3	9	15

Intercropping of millet with sorghum is common in Central Mali. We studied the effect of row arrangement and millet plant density on the productivity of a sorghum/millet intercropping system at Cinzana Research Station, (1 row sorghum:2 millet vs 1:1). The alternate- row arrangement gave significantly higher millet grain yields. However, this improvement in millet growth and yields adversely affected the sorghum growth and grain yields. The intercropping advantage, expressed as the LER, was also greater with the alternate-row arrangement (Table 7).

Increasing millet crop density improved millet grain yields but the competition with associated sorghum reduced sorghum grain yields. The intercropping advantage was greater with the lower millet density.

These preliminary studies on sorghum/millet systems will be continued by introducing other agronomic factors such as variety, fertility, and date of sowing.

Table 7. Influence of row arrangement and millet plant density on the performance of pearl millet/sorghum intercrops Cinzana, Mali, rainy season 1990.

Treatment	Grain yield (t ha^{-1})		LER[1]		
	Sorghum	Cowpea	Sorghum	Cowpea	Total
Row arrangement					
2 sorghum:1 millet	1.9	0.6	0.67	0.38	1.05
1 sorghum:1 millet	1.2	1.2	0.43	0.74	1.17
Millet density (plants m^{-2})					
1.6	1.7	0.8	0.60	0.52	1.12
3.3	1.4	1.0	0.49	0.60	1.09
SE	±0.18	±0.06			
CV (%)	33	33			

1. LER = Land equivalent ratio.

Training

We continued our training activities through in-service training, research scholar short-term training, and long-term degree training.

Table 8. Research personnel from Mali who underwent in-service training at ICRISAT Center, 1990.

Name	Subject
Famory Tounkara	Crop Production
Binogo Ouologuem	Phytogenetics
Seriba dit Ousmane Katile	Phytopathology

During the year, three Malian researchers were sent to ICRISAT Center for in-service training in crop production and crop improvement research (Table 8). Two final-year B.Sc. degree students from Katibougou Agricultural College worked with us from May to December 1990. Three scientists of the Mali national program returned to Institut d'economie rurale (IER) after under going long-term degree training at U.S. and Cameroon Universities through our project fellowships (Table 9). Two senior agronomists of IER are expected to return to Mali after their Ph.D next year (Table 10).

Table 9. Research personnel from Mali trained under the ICRISAT/Mali Bilateral Program in 1990.

Name	Degree	Subject	University
Minamba Bagayoko	M.S	Soil fertility/Cropping systems	University of Nebraska, USA
Karim Traore	M.S	Cereal Breeding	University of Nebraska, USA
Boncana Toure	B.S	Plant Breeding	University of Dschang, Cameroon

Table 10. Researchers from Mali undergoing long term training through ICRISAT and Tropsoils fellowships.

Name	Degree	Subject	University
Mamadou Doumbia	Ph.D	Soil fertility/Cropping systems	Texas A&M, USA
Abdoulaye Sow	Ph.D	Soil and Water	Texas A&M, USA

In addition to these formal training activities, several Malian researchers and technicians continued to work with ICRISAT/Mali scientists. During the year, more responsibilities were assigned to these Malian researchers as they are expected to take full responsibility for research activities in 1991, after the termination of ICRISAT/Mali bilateral program.

Two Malian agronomists were deputed to ICRISAT Sahelian Center for consultation on operational-scale systems research and agronomic data analysis. An ICRISAT Center senior agronomist visited Mali for about 3 weeks to plan soil fertility research for sorghum- and millet-based cropping systems. These consultations and the experience gained by Mali agronomists have enabled the Mali national program to continue without interruption the research activities initiated by the ICRISAT/Mali Bilateral Program.

ICRISAT West African Programs
Senior and Intermediate Staff

ICRISAT Sahelian Center

Administration

R.W. Gibbons
Executive Director
West African Programs and
Director ICRISAT Sahelian Center

A.M.B. Jagne
Regional Administrator

M.D. Diallo
Regional Finance Manager (until Dec 1990)

K.P. Nair
Regional Purchase Manager (until Jan 1991)

A.R. Das Gupta
Manager
Physical Plant Services

K.A. Moussa
Personnel Manager

H. Alsouna
Chief Security Officer

G. Ouoba
Head
Computer Services Unit

Solange Delanne
Executive Assistant (Liaison)

I. Agani
Chief Accountant (deceased Nov 1990)

A. Belemgoagba
Administrative Assistant

I.J. Cachalo
Bilingual Secretary

I. Laouali
Computer Programmer/Analyst

M.A. Ibrahim
Assistant Manager
Physical Plant Services

M.R. Ressy
Electronic Engineer

Kemba Andriamandanona
City Office Attendant

A.R. Tanko
Purchase Officer

Research Programs

Pearl Millet Improvement Program

K. Anand Kumar
Principal Millet Breeder and
Team Leader (on sabbatical leave until Aug 1991)

P. Soman
Principal Agronomist (until Jan 1991)

S.O. Okiror
Principal Millet Breeder/
Regional Trials Officer

J. Werder
Principal Millet Pathologist (until May 1990)

O. Youm
Principal Millet Entomologist (from Dec 1990)

D. Hess
Principal Millet Pathologist (from Aug 1990)

L. Marchais
Principal Geneticist (ORSTOM)

S. Tostain
Principal Geneticist (ORSTOM)

A. Mamalo
Research Assistant

C. Sackitey
Research Assistant

A.A. Cisse
Research Assistant

M. Mahamane
Bilingual Secretary

Groundnut Improvement Program

B.J. Ndunguru
Principal Groundnut Agronomist
and Team Leader

D.C. Greenberg
Principal Groundnut Breeder (until March 1990)

F. Waliyar
Principal Groundnut Pathologist

F. Dougbedji
Research Assistant

N. Garba
Bilingual Secretary

Resource Management Program

C. Renard
Principal Agronomist and Team Leader

M.V.K. Sivakumar
Principal Agroclimatologist

R.J. Van Den Beldt
Principal Agronomist/Agroforestry

M.C. Klaij
Principal Soil and Water Management Scientist
(on sabbatical leave from Sep 1990)

J. Brouwer
Principal Soil Physicist
(From May 1990)

A. Bationo
Principal Soil Chemist (IFDC)

J.H. Williams
Principal Physiologist

J.J. Baidu-Forson
Principal Economist

B.R. N'tare
Principal Cowpea Breeder/Agronomist (IITA)
(until Dec 1990)

M. Powell
Principal Agroecologist and Team Leader (ILCA)

T.O. Williams
Principal Economist (ILCA)

D. Roxas
Principal Nutritionist (ILCA)
(until December)

M. Welte
Program Coordinator and Agronomist
(University of Höhenheim)

Jane Toll
Field Officer for West Africa (IBPGR)

Jane C. Hopkins
Visiting Scientist (IFPRI)

J. Lambourne
Principal Nutritionist, Consultant ILCA
(until Feb 1991)

S. Abdousalaam
Senior Research Assistant

P. Ouedraogo
Senior Research Assistant
(until Jan 1991)

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Research Assistant

M. Djibey
Research Assistant

B. Alzouma
Research Assistant

Y.B. Cisse
Research Assistant

B. Hassane
Programmer

S. Coulibaly
Research Technician

I. Yougbare
Bilingual Secretary

Support Programs

Training

J.Q. Nguyen
Principal Training Officer

N'Diaye Ayele
Bilingual Secretary
Farm Operations

P.G. Serafini
Research Farm Manager
(until July)

Information and Documentation

C. Giroux
Regional Information Officer (until November)

A. Dodo
Translator

F. Gbaguidi
Librarian

A. Janjouna
Secretary/Compositor

West African Sorghum Improvement Program (WASIP) Mali

Administration

R. Vaidyanathan
Administrator (from May)

M. Camara
Farm Manager

D.B. Coulibaly
Bilingual Secretary

S. Niare
Bilingual Secretary

Christine Dolo
Senior Accountant

S. Guindo
Junior Accountant

Research

K.V. Ramaiah
Principal Sorghum Breeder (until December)

M.D. Thomas
Principal Sorghum Pathologist and Cordinator, SAFGRAD/ICRISAT Sorghum Network

F. Coulibaly
Research Assistant

M. Tandia
Bilingual Secretary

C. Luce
Principal Sorghum Breeder (IRAT)

M. Ag Hamada
Research Assistant

Fatoumata Bocoum
Research Assistant

A. Ratnadass
Principal Sorghum Entomologist (IRAT)

B. Cisse
Research Assistant

G. Hoffmann
Principal *Striga* Agronomist (CIRAD)

I. Ba
Research Assistant

Awa Aw
Bilingual Secretary

P. Salez
Agrophysiologist and IRAT Team Leader

K.B. Traore
Research Assistant

A.A. Adesina
Assistant Principal Economist (until November)

D. Sanogo
Senior Research Assistant

S.N. Lohani
Principal Millet Breeder and Acting Team Leader

M.B. Diarra
Research Assistant

Nigeria

Administration

O. Ajayi
Principal Cereal Entomologist and Team Leader

A. Banerji
Administrative Officer

S.A. Toba
Assistant Administrative Officer

M.A. Bello
Assistant Accountant

U. Umolo
Purchase Assistant

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R. Tabo
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Principal Sorghum Breeder

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Research Assistant

D.J. Flower
Principal Plant Physiologist

Farm Development and Operations

A. Ado
Assistant Farm Manager

ICRISAT/Mali Bilateral Program

Administration

S. Toure
Administrative Associate

B. Sogoba
Assistant Accountant

Research

S.V.R. Shetty
Principal Agronomist and Team Leader

N.F. Beninati
Principal Cereals Breeder (until September)

D. Sogodogo
Research Associate (Sotuba)

S. Traore
Research Associate (Cinzana)

Acronyms and Principal Abbreviations

AGRHYMET	Centre régional de formation et d'application en agrométéorologie et hydrologie opérationnelle (Niger)
AICMIP	All India Coordinated Millet Improvement Project
AN	ammonium nitrate
CAN	calcium ammonium nitrate
CGIAR	Consultative Group on International Agricultural Research
CIAT	Centro Internacional de Agricultura Tropical (Colombia)
CILSS	Comité permanent interétats de lutte contre la sécheresse dans le Sahel (Mali)
CIRAD	Centre de coopération internationale en recherche agronomique pour le développement
CNRA	Centre national de recherches agronomiques (Sénégal)
CRSP	Collaborative Research Support Program (USA)
CORAF	Conférence des résponsables africain et français de la recherche agronomique (Sénégal)
CV	coefficient of variation
cv	cultivar
DAS	days after sowing
DM	downy mildew (disease)
ELISA	enzyme-linked immunosorbent assay
ET	evapotranspiration
FAO	Food and Agriculture Organization of the United Nations (Italy)
FYM	farmyard manure
GRU	Genetic Resources Unit, ICRISAT Center (India)
GTZ	Deutsche Gesellschaft für Technische Zusammenarbeit (Germany)
IAR	Institute for Agricultural Research, Ahmadu Bello University (Nigeria)
IBPGR	International Board for Plant Genetic Resources (Italy)
ICRAF	International Council for Research in Agroforestry (Kenya)
ICRISAT	International Crops Research Institute for the Semi-Arid Tropics (India)
IDESSA	Institut des Savannes (Côte d'Ivoire)
IDRC	International Development Research Centre (Canada)
IER	Institut d'économie rurale (Mali)
IFDC	International Fertilizer Development Center (USA)
IFPRI	International Food Policy Research Institute (USA)
IITA	International Institute of Tropical Agriculture (Nigeria)
ILCA	International Livestock Centre for Africa (Ethiopia)
IMZAT	ICRISAT Millet Zone-A Trial
INERA	Institut national d'études et de recherches agricoles (Burkina Faso)
INRAN	Institut national de recherches agronomiques du Niger
INSAH	Institut du Sahel (Mali)
INTSORMIL	USAID Title XII Collaborative Research Support Program on Sorghum and Pearl Millet (USA)
IPDR	Institut pratique du développement rural (Niger)
IPMSN	International Pearl Millet Smut Nursery
IRA	Institut de la recherche agronomique (Cameroon)
IRAG	Institut de recherche agronomique de Guinée
IRAT	Institut de recherches agronomiques tropicales et des cultures vivrieres (France)
IRBET	Institut de recherche en biologie et ecologie tropicale (Burkina Faso)
IRHO	Institut de recherches pour les huiles et oléagineux (France)
ISC	ICRISAT Sahelian Center (Niger)
ISRA	Institut sénégalais de recherches agricoles (Sénégal)
K	potassium

LCRI	Lake Chad Research Institute (Nigeria)
LER	land-equivalent ratio
N	nitrogen
NARS	national agricultural research system(s)
NRI	Natural Resources Institute (UK)
ORD	Organisme régional de développement (Burkina Faso)
ORSTOM	Institut français de recherche scientifique pour le développement en coopération (France)
p	phosphorus
PARP	partially acidulated rock phosphate
PET	potential evapotranspiration
PWRP	Parc-W rock phosphate
S	sulfur
SADCC	Southern African Development Coordination Conference (Botswana)
SAFGRAD	Semi-Arid Food Grain Research and Development (Burkina Faso)
SE	standard error
SRCSS	Section de réglementation et de contrôle des semences sélectionnées
SSP	single superphosphate
TROPSOILS	Soil Management Collaborative Research Support Program (Texas A&M University, USA)
TRP	Tahoua rock phosphate
TSP	triple superphosphate
USAID	United States Agency for International Development
WASIP	West African Sorghum Improvement Program
WASAT	West African Semi-Arid Tropics
WCAMRN	West and Central African Millet Research Network
WCASRN	West and Central African Sorghum Research Network
WUE	water-use efficiency