Soil Tillage and Windbreak Effects on Millet and Cowpea: II. Dry Matter and Grain Yield

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ABSTRACT

In the West Africa Sahel, sand storms occurring early in the growing season may severely damage emerging crops. This study was conducted to determine the influence of ridges and windbreaks on growth, water use and grain yield of millet, *Pennisetum glaucum* (L.), and cowpea, *Vigna unguiculata* (L.) Walp. A field trial was carried out from 1985 to 1987 on a Psammentic Paleustalf in southern Niger using 12 ha of land fallowed over the previous 5 yr. Treatments for millet and cowpea were flat and ridged soil preparation and windbreaks spaced at 6, 20, 40, and 90 m. Total annual rainfall was 558, 641, and 363 mm in the 3 yr of the experiment; onset and distribution of the rains varied. Millet total dry matter (TDM) increased as total water use increased from 250 to 400 mm. Ridging did not change total dry matter or grain yield in millet but increased cowpea grain yield by 90 and 300 kg ha^{-1} in 2 of the 3 yr. Protection by windbreaks spaced 6 and 20 m apart resulted in a 48 to 90% increase in early millet TDM and a 74 to 89% improvement of cowpea ground cover. However, these early effects were not sustained throughout the growing period. Average TDM at maturity and grain yields were similar in all windbreak spacings for millet and cowpea. Although windbreaks may not increase yields of two important Sahelian crops, they may help to stabilize longterm crop production by conserving the soil and providing additional marketable commodities if an appropriate selection is made of type of windbreak and species planted.

POOR CROP ESTABLISHMENT is a major problem in the West African Sahel. One important reason is sandblasting or burying of seedlings by sandstorms occurring early in the growing season (ICRISAT, 1986). A modification of micro-climatic and soil conditions, aiming at the protection of emerging crops from abrasive and erosive winds may thus be decisive to improve early crop growth and final yield (Armbrust, 1984). The influence of soil preparation and of windbreaks consisting of natural savannah vegetation belts on microclimate and soil parameters was discussed in a previous paper (Banzhaf et al., 1992). The objectives of this study were (i) to determine the effect of changes in climatic and soil conditions on early growth of millet and cowpea, (ii) to verify the influence of modified growing conditions on TDM of both crops and water use of millet, and (iii) to examine the impact of soil preparation and windbreaks on grain yield in a Sahelian farming system's setting of realistic size.

MATERIALS AND METHODS

Experimental Design, Planting, and Fertilization

The field layout with two land preparation treatments (ridged and flat planted), four windbreak distances (6, 20, 40, and 90 m) and two crops arranged in a split split-plot design with three replications was described previously (Banzhaf et al., 1992).

Millet, cultivar CIVT, was planted immediately after land preparation on 27 June 1985, 29 May 1986, and 14 July 1987. Rows were spaced 0.75 m apart and interrow spacing was 1.0 m. Planting was done by putting 20 to 40 millet grains in a hole, hereafter referred to as a hill. Millet was thinned to three plants per hill at the five-leaf stage. Cowpea cultivar TN 88-63 was planted on 29 June 1985, 19 June 1986, and 17 July 1987 by seeding 5 to 10 grains per hill in a 0.75- by 0.5-m planting pattern. To compensate for declining fertility, P and K were applied on all plots as follows: No P and K fertilizers were applied in 1985, however, in 1986, plots received 30 kg ha^{-1} of P and, in 1987, 25 kg ha^{-1} of each P and K before planting. Nitrogen at 30 kg ha^{-1} was applied to all plots at millet tillering during each year of the experiment. Nitrogen was applied as calcium-ammonium nitrate, P as triple superphosphate, and K as KCl.

Data Collection

Plant growth data were collected at nine locations across the whole plot in each of the three replicates when windbreak distances were 6 ,20, and 40 m and at eleven locations in the 90-m windbreak distance treatment. Sampling areas measured 7.5 m^2 corresponding to 10 hills of millet and 20 of cowpea. The data of each plot were averaged. Ground cover of cowpea was estimated in 1987 with a 1.0- by 0.6-m frame subdivided by Nylon strings into a 0.2- by 0.2-m grid. In the field, the frame was held at 0.5 m above ground and arranged in a way that a first plant matched with a cross of the grid. Percent cover was estimated by counting the number of crosses that coincided with plants within the frame, all 24 grid crosses corresponding to 100%. In 1987, an early dry matter harvest was conducted for millet at the five-leaf stage. In all three cropping seasons, millet and cowpea were harvested 10 d after the onset of flowering. At this stage, both crops have usually reached their maximum green matter and leaf area (Maiti and Bidinger, 1981; Wien and Summerfield, 1984). Final TDM was harvested after physiological maturity of seeds was reached. In millet, this stage was determined by the "black layer formation" (Fussel and Dwarte, 1979), whereas in cowpea, this stage was defined by the change in color of 95% of pods from green to brown.

Above-ground plant material was separated into stems, leaves, and ears or pods and dried to constant weight at 60°C in a forced-draft oven. Prior to drying, photosynthetically active leaf tissue of millet was passed through a video leaf area meter (Delta-T Devices, Ltd, Cambridge, England) to determine leaf area. Leaf area index was calculated as leaf area divided by plot area.

To estimate total growing season water use of millet, the difference between precipitation (mm) received from soil preparation to final harvest and the soil water recharge during the growing season was determined. The result was taken as a proxy for the total water use of the millet crop. Runoff was not measured in our experiments but visual assessment suggested that no important runoff occurred from the fairly level plots. On the other hand, some deep percolation may have occurred in 1986 during high rainfall periods (Bley et al., 1991).

All yield data are based on area harvested. No adjustments were made for the space used by the windbreaks. This pro-

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Abbreviations: TDM, total dry matter. *** Significant at the 0.001 probability level.

Table 1. Effects of windbreak distance on total dry matter of millet at the five-leaf stage in 1987.

	Distance between windbreaks			
	m			
	6	20	40	90
	(kg ha^{-1})			
Total dry matter	33.5	26.1	20.1	17.6
LSD (0.05) = 10				

cedure was chosen because the area used by the windbreaks was not considered idle. The dry matter produced by the natural vegetation of the windbreaks can be locally used or sold on the market as a valuable fodder supplement or as fire wood.

Data Analysis

Data from both sub-subplot treatments (crop) were analyzed separately using a split-plot model. Because treatments were kept constant in each plot over years, the normally distributed yearly crop data were regarded as repeated measurements and processed using repeated measures analysis of variance (SAS, 1986).

RESULTS

Climatic Conditions

Average annual temperature at Sadoré is 29°C with very little variation over years. Total annual rainfall was 558 mm in 1985, 641 mm in 1986, and 363 mm in 1987, the first 2 yr comparing favorably with the long-term average of 574 mm (West et al., 1984). The third year of this research, 1987, not only fell short in total rainfall, the rainy season also started unusually late with irregular rainfall events often smaller than 10 mm (Fig. 1). Also, the number of sandstorms without subsequent rainfall was greater than usual, causing cover-up and abrasion stress to both millet and cowpea.

Early Crop Growth

In 1987, there was no significant effect of flat vs. ridged land preparation treatments on early crop growth, judging from percent ground cover of cowpea and TDM data of millet at the five-leaf stage (data not shown). However, the protection of young crops by windbreaks proved to be decisive for establishment and early growth in 1987. Millet TDM at the five-leaf stage was 90% greater with effective wind and sand blast protection in the 6-m windbreak distance than in the control with 90 m between windbreaks. Millet growth decreased gradually with less wind protection in the wider windbreak distances (Table 1). Similarly for cowpea, percentage of ground cover 40 and 50 d after planting was significantly greater in the narrow spaced windbreak treatments than with wide spacings (Table 2).

Dry Matter after Flowering and at Maturity

There was a significant effect of years on TDM of millet and cowpea at 10 d after flowering and at maturity. Total dry matter production at 10 d after flowering of millet in 1986 and 1987 was 71 and 36%, respectively, of the amount obtained in 1985. At maturity, the amounts for 1986 and 1987 were 88 and 34%, respectively, of the TDM obtained in 1985. The earliest year was thus the most favorable for millet growth, but even under those conditions, an LAI of only 1.5 was reached (Table 3). For cowpea, however, 1986 appeared to present better growing conditions than either 1985 or 1987 with TDM 10 d after flowering reaching only 44 and 22%, respectively, of the amount produced in 1986 (Table 4).

Table 2. Effects of windbreak distance on ground cover of cowpea in 1987.

	Distance between windbreaks			
	m			
Days after planting	6	20	40	90
	%			
30	13a†	13a	10a	10a
40	37b	32ab	22a	21a
50	52b	39a	28a	28a

† Within rows, means followed by the same letter do not differ significantly at an LSD (0.05).

When averaged over years, TDM data of millet did not reveal any significant effect of soil preparation or windbreak treatments (Table 3). However, windbreak effects in individual years indicated some trends. In 1985, TDM harvested 10 d after flowering included significantly greater amounts of stems and leaves in the 20-m windbreak distance than in the 90-m control. In 1986, the 40-m treatment produced a slightly higher amount of dry matter than any of the other windbreak treatments. By contrast, in the stressful year of 1987, greatest amounts of TDM at 10 d after flowering were produced in the well-protected 6-m windbreak treatment. However, our design did not allow us to measure this tendency as statistically significant. At millet maturity, no straw or TDM response to soil preparation or windbreak treatments could be detected, as TDM and straw yields were numerically very similar over all treatments in any year (Table 3).

Cowpea growth 10 d after flowering was clearly favored by ridged soil preparation which increased plant dry weight by 60%. This effect of ridging was significant in 1985 and 1986 and still numerically evident in 1987 (Table 4). Looking at windbreak effects on cowpea in individual years, a similar trend as in millet was observed. As wind protection increased at narrower windbreak spacings, TDM and in particular leaf dry matter was positively influenced achieving greatest amounts in the 6-m windbreak spacing in 2 out of 3 yr (Table 4).

Millet Water Use

Across the three cropping seasons, TDM of millet increased up to a total water use of over 400 mm, the highest level obtained in this experiment. Similar total growing season water use data for millet in this region were reported by Garba and Renard (1991). However, when looking at individual years, a distinctly lower water use and dry matter production was observed in 1987 as compared to the other 2 yr (Fig. 2).

Grain Yield

Grain yields of both, millet and cowpea, were clearly related to the year. In millet, both TDM and grain yield showed a significant tendency of decline in the third year (Table 3). The decline in grain yield appeared to be related to an almost 50% lower number of heads per hill. Compensation by a significant increase in thousand-seed weight could not offset the reduced head numbers. The extremely poor cowpea yield in 1987 was clearly reflected in the lower number of pods per hill (Table 4).

Averaged over the three cropping seasons, millet grain yield was unaffected by either soil preparation or windbreak distances. An analysis of these factors for individual years did not change this general picture with the exception of windbreak effects in 1987, which showed a slightly increased grain yield at the windbreak distance of 40 m (Table 3).

Ridged soil preparation increased average grain yield of cowpea by 27%, with a particularly visible effect in 1986. In 1986, numerically but not significantly greatest yields were achieved with windbreak spacings of 20 or 40 m (Table 4).

DISCUSSION

The Year Effect

Year was the only factor which had a highly significant effect on both crops. In 1985, the onset of the rainy season occurred in mid-June, and precipitation steadily increased towards the month of August, then decreased until mid-September providing a 3-mo growing season with even rainfall distribution. The highest millet grain production and almost the highest cowpea production was obtained in this year. In 1986, total rainfall was 67 m above the long-term average. However, rainfall distribution at the onset of the growing season was less than optimal. One large rain occurred at the beginning of the season followed by almost no precipitation for 3 wk. This early stress may have affected millet performance whereas cowpea probably escaped early stress due to later seeding. The third year was a typical drought year with one rain of 14 mm opening the growing season at the end of May followed by a 1-mo drought period leading to widespread crop failure and replanting by mid-July. This was too late for either millet or cowpea to reach normal yield. The amount of rainfall received during the three growing seasons varied greatly. However, moisture available to crops may not have been limiting except in 1987 when water supply was both low and untimely, which resulted in low dry matter production. Research conducted in the region by several authors (Payne et al., 1990; Agnew, 1991; Bley et al., 1991) confirms that, in southwest Niger with an average annual precipitation of 500 to 600 mm, insufficient water supply frequently is not the main cause for low productivity in millet The major yield-limiting factor, instead, is the low availability of plant nutrients, especially P (Bationo et al, 1987). Furthermore, it appears that not the amount of rainfall per se but rather the circumstances under which it occurs, such as time of onset, distribution, and sand storms preceding rains are important determinants of potential crop production in a given year. Even in the best year for millet, the average LAI 10 d after flowering did not rise above 1.5 and average TDM and grain yields of only 3.6 and 0.7 t ha^{-1}, respectively, were harvested. By contrast, pearl millet grown at high densities in India reached LAIs of 6 to 7 resulting in TDM weights at maturity of 15 to 20 t ha^{-1} and grain yields of up to 5.5 t ha^{-1} (Carberry et al., 1985). Compared to this high potential, the low LAI values achieved in our millet crops point to a source-limited situation which was not corrected by any of the agronomic practices we were testing in this experiment.

Soil Preparation

Soil tillage has been shown to be a decisive factor in soil conservation and wind erosion control in the

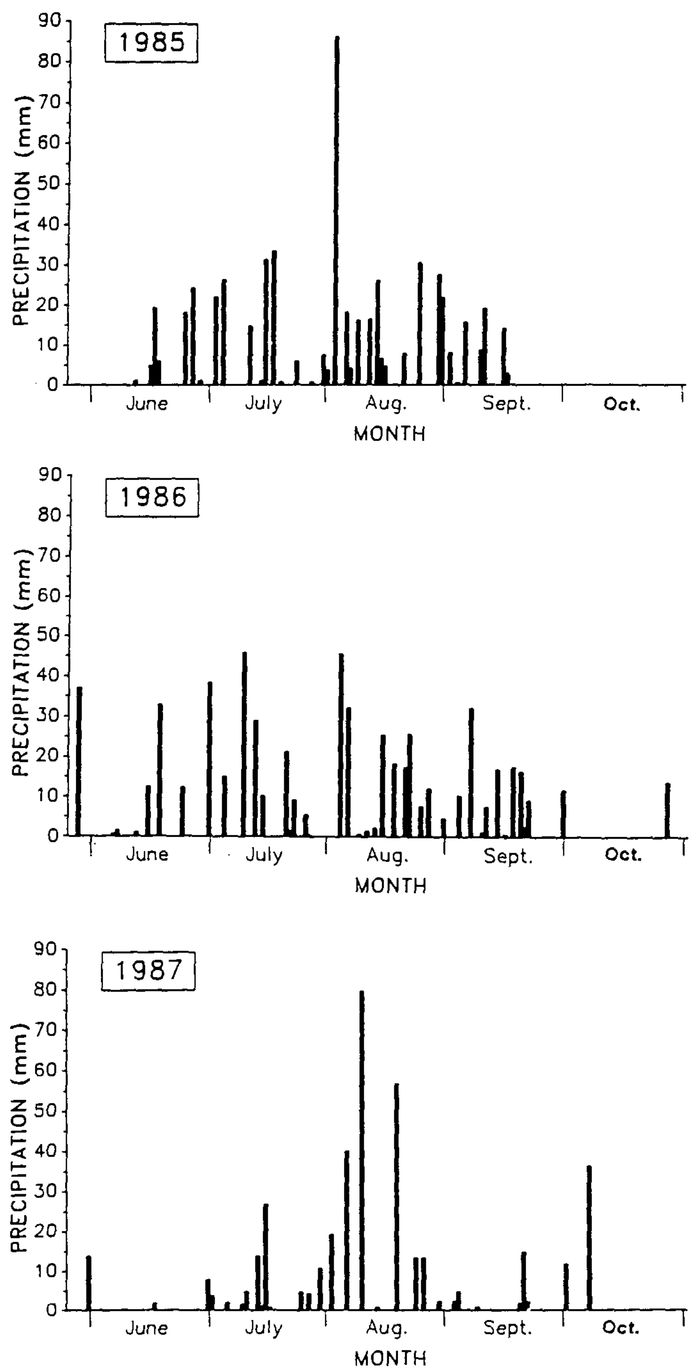

Fig. 1. Daily precipitation during the 1985, 1986, and 1987 growing seasons.

Table 3. Effects of year, soil preparation (SP), and windbreak (WB) distance on dry matter, leaf area index, yield, and components of yield in millet.

	10 d after flowering				At maturity				
	Dry matter weight				Dry matter weight				
	Stems	Leaves	Total	LAI	Straw	Grain	Total	1000-seed weight	Heads per hill
	kg ha^{-1}				kg ha^{-1}			g	
Year									
1985	1840A‡	630A	2470A	1.5A	2900A	740A	3640A	8.0B	4.2A
1986	970B	780A	1750B	1.3A	2590A	590B	3190A	7.6C	2.4B
1987	30C	370B	890C	0.5B	1020B	220C	1230B	8.5A	2.2B
SP									
flat	1040	560	1590	1.1	2150	510	2660	8.2	2.8
ridged	1190	620	1810	1.2	2200	520	2710	7.9	3.0
Windbreak distance									
6 m	1180	590	1770	1.1	2070	460	2530	8.2	2.7
20 m	1290	630	1920	1.2	2260	540	2800	8.1	3.1
40 m	1050	600	1650	1.1	2180	510	2690	8.0	3.1
90 m	940	540	1480	1.0	2180	540	2730	7.9	2.9
Year × SP									
1985									
flat	1910	660	2570	1.6	3060	790	3850	8.4	3.9
ridged	1770	590	2360	1.5	2750	689	3430	7.7	4.4
1986									
flat	620	610	1240	1.0	2320	530	2840	7.5	2.2
ridged	1320	940	2260	1.6	2870	660	3530	7.7	2.6
1987									
flat	570	400	970	0.6	1070	220	1290	8.5	2.4
ridged	480	340	820	0.5	970	210	1180	8.4	2.1
Year × WB									
1985	†	†	†	NS	NS	NS	NS	NS	NS
6 m	1950ab	610ab	2560ab	1.5	2800	730	3530	8.3	3.9
20 m	2500a	750a	3250a	1.7	2940	720	3660	8.0	4.2
40 m	1570ab	620ab	2180ab	1.5	2910	700	3610	7.9	4.5
90 m	1350b	520b	1870b	1.3	2970	800	3760	8.0	4.2
1986	NS	NS	NS	NS	NS	NS	NS	NS	NS
6 M	950	730	1680	1.2	2440	520	2960	7.7	2.2
20 m	930	780	1700	1.3	2820	670	3490	7.8	2.7
40 m	1000	810	1810	1.4	2470	570	3040	7.5	2.4
90 m	1010	780	1790	1.3	2660	610	3270	7.6	2.5
1987	NS	NS	NS	NS	NS	†	NS	NS	NS
6 m	640	410	1060	0.6	970	140b	1110	8.7	2.1
20 m	440	350	800	0.5	1020	230ab	1240	8.5	2.4
40 m	570	380	950	0.5	1160	270a	1430	8.8	2.4
90 m	450	320	770	0.4	930	220ab	1150	7.9	2.0
				Analysis of variance					
Year (Y)	***	***	***	***	***	***	***	**	***
SP	NS	NS	NS	NS	NS	NS	NS	*	NS
WB	NS	NS	NS	NS	NS	NS	NS	NS	NS
Y × SP	*	NS	*	NS	NS	NS	NS	*	NS
Y × WB	*	NS	†	NS	NS	NS	NS	NS	NS
SP × WB	NS	NS	NS	NS	NS	NS	NS	NS	NS

†,*,**,*** F-test significant at the 0.1, 0.05, 0.01, and 0.001 probability levels, respectively; NS is not significant at $P > 0.1$.
‡ Means followed by the same uppercase letter do not differ significantly using an F-test at the 0.01 probability level; means followed by the same lowercase letter do not differ significantly using a Tukey test ($P < 0.1$).

USA. In a study on a fine sandy loam soil, ridges of up to a 0.25-m height or coverage of 60% of the soil surface with non-erodible clods reduced soil losses by wind up to 90% (Fryrear, 1984). In the sandy soils of the Sahel, no clod formation occurs and the surface roughness created by ridges does not persist for long because ridges dry out and are leveled by wind or heavy rainfall. This may explain why we did not observe differences in the amount of wind-blown soil particles collected in the first 0.5 m above ground with ridged as compared to flat soil treatments (Banzhaf et al., 1992). However, ridging could have created a zone of lose soil easily penetrated by a juvenile root system, thus overcoming the effects of soil compaction and crusting, which are frequent problems in the Sahel. Also, ridging might have allowed the concentration of small amounts of crop residues and dust deposits on the soil surface around the emerging seedlings, leading to an improved nutrient supply during early crop growth. The positive reaction of cowpea to ridging may actually be a result of these factors rather than one of reduced wind erosion in the ridged treatment. In millet, on the other hand, the response to ridging was inconsistent. A tendency for improved growth and grain yield was only observed in 1986 when climatic conditions allowed the ridge structure to persist during the first 3 wk after planting.

Wind Protection

Downes et al. (1977) have shown that sand blasting reduced seedling survival, early growth, and yield of

Table 4. Effects of year, soil preparation (SP), and windbreak (WB) distance on total dry matter, yield, and components of yield in cowpea.

	10 d after flowering				
	Dry matter weight			At maturity	
	Stems	Leaves	Total	Pods per hill	Grain yield
	kg ha^{-1}			no.	kg ha^{-1}
Year					
1985	430B‡	280B	710B	43A	810A
1986	940A	670A	1600A	44A	900A
1987	210C	150C	360C	6B	80B
SP					
flat	380	310	690	28	530
ridged	670	420	1100	34	660
Windbreak distance					
6 m	590	410	990	27	540
20 m	510	370	880	33	630
40 m	500	340	840	32	640
90 m	510	340	850	32	570
Year × SP					
1985	*	*	*	NS	NS
flat	320	220	530	38	750
ridged	550	340	880	49	860
1986	*	NS	†	†	†
flat	630	5609	1190	39	730
ridged	1250	770	2020	49	1060
1987	NS	†	NS	NS	NS
flat	200	140	340	7	90
ridged	220	160	380	5	70
Year × WB					
1985	NS	†	NS	NS	NS
6 m	500	310a	810	41	700
20 m	460	280ab	720	46	790
40 m	350	250b	590	41	930
90 m	420	270ab	690	46	800
1986	NS	NS	NS	NS	NS
6 m	930	690	1620	37	850
20 m	870	700	1570	48	1040
40 m	1010	650	1650	43	880
90 m	950	630	1580	43	810
1987	**	†	*	NS	NS
6 m	330a	220a	550a	4	60
20 m	192b	145ab	337b	6	70
40 m	150b	122b	272b	7	100
90 m	150b	120b	270	8	90
		Analysis of variance			
Year (Y)	***	***	***	***	***
SP	**	†	*	NS	†
WB	NS	NS	NS	NS	NS
Y × SP	NS	NS	NS	NS	NS
Y × WB	NS	NS	NS	NS	NS
SP × WB	NS	†	NS	NS	NS

†,*,**,*** F-test significant at the 0.1, 0.05, 0.01, and 0.001 probability levels, respectively; NS is not significant at $P > 0.1$.
‡ Means followed by the same uppercase letter do not differ significantly using an F-test at the 0.001 probability level; means followed by the same lowercase letter do not differ significantly using a Tukey test ($P < 0.1$).

cabbage, carrot, onion, and pepper seedlings in wind-tunnel experiments. However, no effects on seedling survival were observed for cowpea. Final plant fresh weight and grain yield of cowpea were actually increased by sand blasting as the total kinetic effect of sand storms rose from 0 to 322.9 μJ. The surprising tolerance of cowpea to sandblasting in Downes' experiment was related to the stimulation of new growth after injury by the simulated sandstorm. Windbreaks in our study were shown to effectively reduce wind speed and amount of air-blow soil particles (Banzhaf et al., 1992). Furthermore, early ground cover of cowpea, an indirect measure of growth,

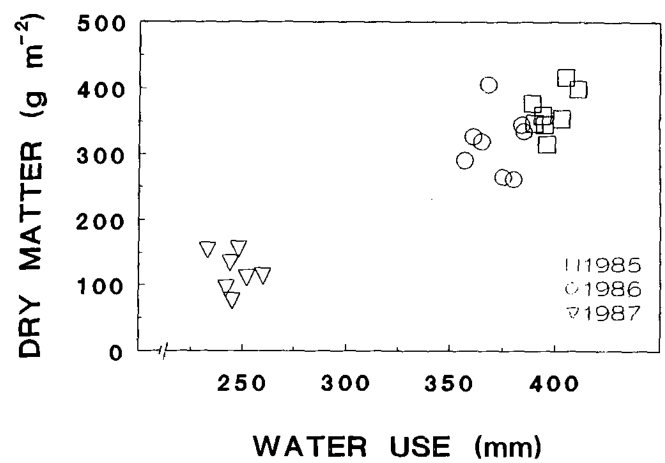

Fig. 2. Relationship between total water use and total dry matter yield of millet. Symbols represent treatment means of the three replications for 1985–1987.

was significantly enhanced by protection from wind and sand blasting in the 6-m windbreak spacing. This effect appeared to continue until 10 d after flowering when leaf dry weight, and in 1987 also total plant dry weight, was positively related to wind protection. However, no significant windbreak effects on grain yields were observed, confirming the ability of cowpea to compensate for early sand blasting damage.

Similarly, the significant positive early effect of wind protection on millet growth in 1987 disappeared at later growth stages, and no significant effect of windbreak treatments on TDM at maturity could be observed in any of the 3 yr. Grain yield in millet was clearly dependent on the amount of TDM at maturity (r = 0.96***) Thus, no significant average effect of windbreaks on millet grain yield was found. As was suggested previously (Banzhaf et al., 1992), this might be related to competition between the narrow spaced wind break vegetation and millet for soil water, and possibly also plant nutrients, rather than to direct wind effects.

We conclude that even if significant positive effects on early growth and crop cover can be derived from wind protection in the Sahelian environment, influence on grain production remains elusive. This is confirmed by other windbreak studies conducted in the region. At the ICRISAT Sahelian Center, millet was grown over 4 yr between windbreaks consisting of artificially planted *Andropogon gayanus* Kunth without any grain yield advantage compared to the unprotected crop (Renard and Vandenbeldt, 1990). In the Majjia Valley of south central Niger, CARE International has monitored farmers growing millet between windbreaks established with neem trees, *Azadirachta indica* Adr. Juss., without finding a significant influence of windbreaks on millet grain yield (Long et al., 1986). Both studies, however, point out numerous advantages derived from windbreaks. The study at ICRISAT Sahelian Center showed an effective trapping of large amounts of sand and dust in and between the *A. gayanus* strips. This should have contributed to conserving the soil and some of the nutrients contained in the dust. Both *A. gayanus* and the neem trees also contributed construction materials and fire wood. Our windbreaks, consisting initially of natural savannah vegetation, might be attractive to local farmers because of their easy establishment and low cost. However, their usefulness in terms of providing by-products was only gradually improved by interplanting trees. Contributions of such valuable market commodities as construction materials, firewood or fodder—if harvested—would have been small at the beginning. On the other hand, planted windbreaks provide marketable products early but require much higher capital investment for their establishment. A careful socioeconomic analysis would be necessary to decide on the feasibility and acceptability of either type of windbreak. Even without a yield-increasing effect on food crops, a number of other reasons, such as soil conservation and the production of marketable commodities in the windbreaks, may provide ecological and economic motivations for their establishment. Achieving these benefits for specific local conditions depends on a careful choice of type of windbreak and species planted.

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