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EFFECTS OF WINDBREAK SPECIES AND MULCHING ON WIND EROSION AND MILLET YIELD IN THE SAHEL

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SUMMARY

In an on-station agroforestry experiment conducted in south-west Niger, the effects of seven windbreak species and of a soil mulch made from crop residue on wind erosion and pearl millet (*Pennisetum glaucum*) production were monitored. Within a distance of 20 m, strips of the perennial grass, *Andropogon gayanus*, reduced total annual soil flux by 6–55% and hedges of *Bauhinia rufescens* 2 m in height reduced soil flux by 47–77% compared with unsheltered control plots. No significant overall windbreak effect on millet stover and grain yields was found. In contrast, erosion reduction and yield increases due to mulch application were highly significant. Soil mulch is a promising alternative to complex windbreak–millet cropping systems in regions where direct economic benefits for farmers are not ensured by windbreaks.

INTRODUCTION

Windbreaks in agricultural systems can improve micro-climatic conditions for crop growth, halt wind erosion, stabilize mobile dunes and thus contribute to sustained soil fertility leading to stable and higher yields. By-products of trees provide farmers in many countries with useful material or cash. However, the interactions between trees, soils and crop growth in semi-arid regions are barely understood yet. In particular, data on wind erosion effects are scarce. Conclusions about the effects of windbreaks on crop yields have been contradictory (Ben Salem, 1991; Kaisin, 1994). Despite promising results with agroforestry systems, it cannot be concluded that in the Sahelian and Sudanian zones of West Africa the incorporation of trees in cropping systems is always suitable everywhere (Kessler and Breman, 1991; Kaisin, 1994).

Several windbreak systems have been investigated at the ICRISAT Sahelian Center (ISC) near Niamey, Niger, during the last decade. Natural savanna vegetation shelters of 0.6–1.0 m in height decreased wind speed, amounts of windblown soil and potential evaporation, but had no significant impact on millet

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and groundnut yields (Banzhaf *et al*., 1992; Leihner *et al*., 1993). Strips of the perennial grass *Andropogon gayanus* 10 m in width trapped large amounts of blown soil, but had no effect on millet yields (Renard and Vandenbeldt, 1990). Brenner *et al*. (1995) concluded from a field trial with millet sheltered by neem trees (*Azadirachta indica* A. Juss) 6 m in height that the advantage of shelters lies primarily in enhanced vegetative crop growth during the middle of the growing season. They found that millet germination and emergence was delayed by shelters because of increased soil surface and air temperatures. A soil moisture conservation function of windbreak systems should not be expected in the Sahel (Smith *et al*., 1997a; Brenner *et al*., 1995). At ISC, where the water table is at a depth of 35 m, both trees and crops must fulfill their water requirements from the top 2–3 m soil throughout the year (Smith *et al*., 1997b). On sites with accessible groundwater at depths of 6–8 m, spatial complementarity in the use of water resources by trees with tap roots and crops in windbreak systems is improved (Smith *et al*., 1997b). The neem windbreaks in the Majjia Valley in Central Niger, the most mentioned windbreak plantation in West Africa, are able to use deep reserves of soil water, but, where millet yields were increased by 26% compared with unsheltered controls, within a 110-m area behind neem trees 11 m in height, the increase was not significant (Long and Persaud, 1988).

The effects of windbreaks on erosion, micro-climate and on the competition for light, nutrients and water between windbreak vegetation and cultivated crops depend on the species of both windbreaks and crops, management and resource availability. The right choice of adapted tree and shrub species is therefore one of the most important factors for the planning of new systems (Kessler and Breman, 1991; Vandenbeldt, 1991). Furthermore, alternatives to windbreaks for wind erosion control (for example, soil mulching) are needed for areas where farmers hesitate to adopt windbreaks. Mulching with crop residue or with twigs not only reduces wind erosion and traps blown soil, but also stimulates crop growth, stabilizes and increases yields and is easy to apply (Lamers, 1995; Michels *et al*., 1995a). The objective of this research was to determine the interactions between windbreaks and crop residue mulch on wind erosion, soil properties and the production of pearl millet. The study was part of a systems analysis with parallel research on tree production and socio-economic evaluations (Lamers, 1995).

MATERIALS AND METHODS

Experimental site

An agroforestry field experiment was conducted at ISC, Niger (lat 13°15′N, long 2°18′E, altitude 240 m) from May 1991 until November 1993. The soil is classified as a Psammentic Paleustalf (sandy, siliceous, isohyperthermic) of the Labucheri soil series, according to the US Soil Taxonomy (West *et al*., 1984). Total rainfall was 603 mm in 1991, 585 mm in 1992, and 542 mm in 1993. The average annual rainfall (1931–1990) at Niamey is 545 mm (Sivakumar *et al*., 1993). South-west winds prevail during the rainy season, but do not cause erosion; eastern wind storms regularly precede rainfall events and frequently cause wind erosion.

Windbreak design and mulch application

In August 1988 eight windbreak species were transplanted from the nursery into a randomized block design with three replications (Fig. 1). The species were the perennial grass *Andropogon gayanus*, the Australian shrub *Acacia holosericea* A. Cunn Ex G. Don., the indigenous shrub and tree species *Acacia nilotica* var. *adansonii*, *Acacia senegal* (L.) Willd., *Bauhinia rufescens* Lam., *Faidherbia albida* Del. (syn. *Acacia albida* Del.) and the neem tree *Azadirachta indica*. *F. albida* trees are very common in Sahelian parkland systems; they usually loose their leaves at the onset of the rains. Three other species were also transplanted but without replications and thus not considered in this study. Each species was planted in a double staggered row configuration 50 m in length aligned in a north–south direction, perpendicular to the prevailing erosive wind direction. Plant spacing was 3 m in the row and 1.5 m between rows. The distance between the centres of the windbreaks was 30 m. Beginning in 1990 the windbreaks were trimmed to a height of 2 m and a frontal silhouette width of 3.5 m prior to each rainy season. Field plots westwards of these windbreaks were prepared for millet cultivation. Plots without any windbreak served as the control. The windbreaks occupied 11.7% of the total plot area, giving 220 shrubs ha^{-1} cultivated land. The depth of the water table was about 35 m.

A surface mulch application using millet stover at a rate of 2 t ha^{-1} served as an additional or alternative wind erosion control measure. The mulch was applied on the soil in one half of each plot (resulting in a split-plot layout with windbreak species as the main factor) prior to each rainy season.

Cropping system

The millet cultivar CIVT (Composite Intervariétale de Tarna) was sown manually in planting holes spaced 1×1 m on 26 May in 1991, 27 May in 1992, and 7 June in 1993. The first millet row was at a distance of 2.75 m from the centre of the windbreak. Single superphosphate was broadcast at the recommended rate of 13 kg P ha^{-1} before sowing. Calcium-ammonium nitrate was applied close to each planting hole as a split dose at tillering (30 kg N ha^{-1}) and at shooting (15 kg N ha^{-1}). The field was weeded manually at three and ten weeks after sowing and plants were thinned to three plants per hole at three weeks after sowing. As it is local practice, birds were kept off the millet field after grain filling.

Wind erosion measurements and soil chemical properties

Due to technical limitations two windbreak species had to be selected for erosion measurements in addition to the control plots without a windbreak. *A. gayanus* was chosen as representative of a porous grass barrier and *B. rufescens* as a dense shelter species. BSNE soil erosion samplers (Fryrear, 1986) were placed at

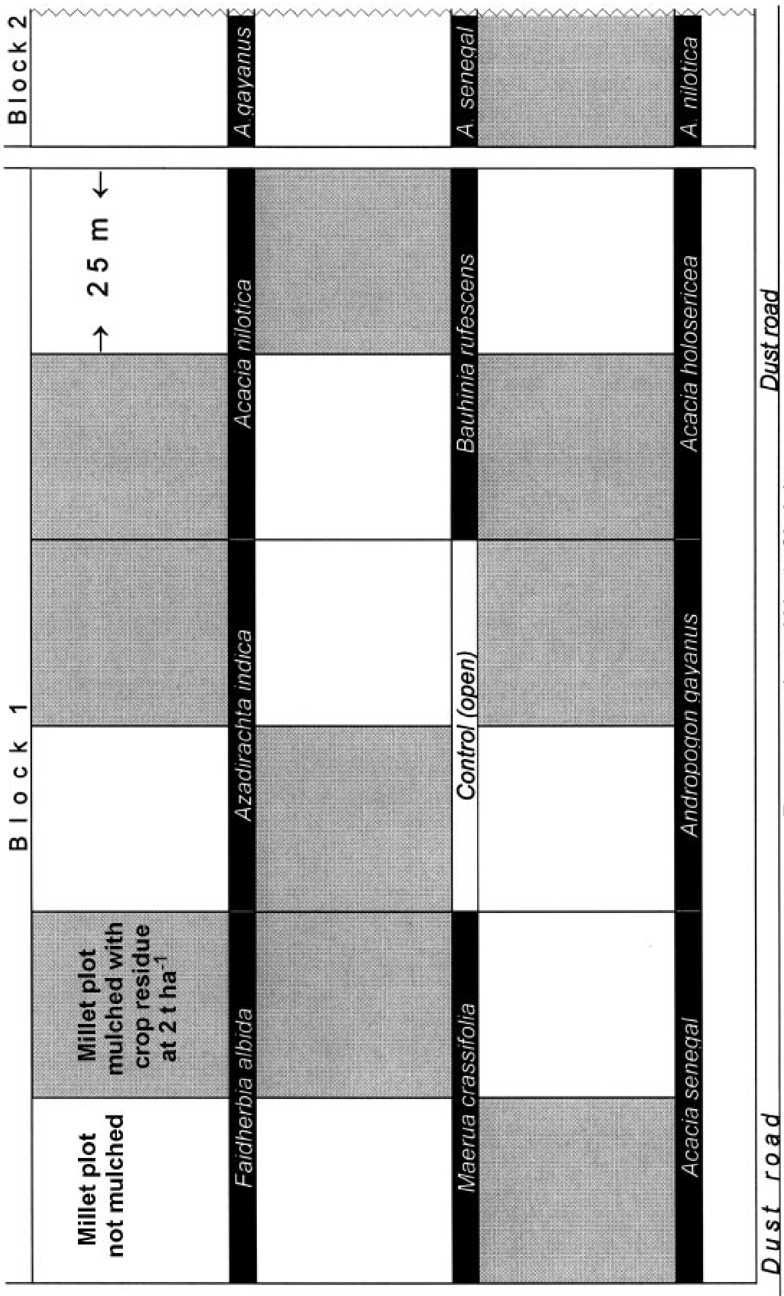

Fig. 1. Field layout of windbreak–millet systems with and without applied mulch (split plot design) showing one out of three blocks.

distances of 5, 10 and 15 m from the border of the windbreak in each sub-plot at a height of 0.1 m. The vertical sampler opening was 20 mm wide and 50 mm high, thus sampling a range from 0.075 to 0.125 m above the soil surface. Soil flux amounts obtained from the samplers describe horizontal soil flux but not soil loss from the ground. At the end of each erosion event, the captured material was oven-dried and weighed.

Soil samples from the bare sub-plots of *A. gayanus*, *B. rufescens* and the control were taken in May 1991 and May 1993 at distances of 1, 3 and 10 m from the windbreaks or from the plot edge in the control, and at 3 soil depths of 0–0.1, 0.1–0.2 and 1–2 m. Samples were air-dried and sieved to pass a 2-mm screen. Soil was analysed for total nitrogen by the micro-Kjeldahl method (Bremner and Mulvaney, 1982), pH (1 : 2.5 (w/w) soil: 0.01 M KCl), organic carbon (Walkley and Black, 1934), and Bray-I phosphorus (Olsen and Sommers, 1982). Concentrations of exchangeable calcium and magnesium were measured by atomic adsorption, and sodium and potassium by flame emission spectrophotometry, after extraction with 1N ammonium acetate. Exchangeable aluminium and total acidity were determined according to McLean (1982).

Millet yields

At physiological maturity, the survival of millet stands (with at least one plant) was recorded. Samples of 20 m^2 were harvested separately from each millet row parallel to the windbreaks and divided into millet panicles and stover. Panicles were oven-dried at 60 °C to constant weight and threshed manually. Stover was left in the field and weighed after sun-drying for three weeks. Means of each yield parameter were calculated for three categories of lateral distance from the windbreak: 1–3 m, 4–9 m and 10–20 m. Plot means were calculated over a 20-m lateral distance from the windbreak, which was ten times the windbreak height. Yield data were based on the effectively harvested area, not the area occupied by the windbreaks.

Data analysis

Analyses of variance were performed using a general linear model (GLM) procedure (SAS Institute, 1990). Soil flux data were regarded as repeated measurements over both time (erosion events) and space (lateral distances from windbreaks) and processed using the repeated-measures option within GLM (Milliken and Johnson, 1984). Similarly, soil chemical properties were evaluated over both lateral distance from windbreaks and at soil depths. Millet yields were regarded as repeated measurements over years. F-tests were done and contrasts of interest were calculated for interactions between treatments and the repeated factors. Fisher's protected least significant difference (l.s.d.) was used to compare treatment means of *A. gayanus*, *B. rufescens* and the control. Tukey's honest significant difference (h.s.d.) was used to compare means among the seven windbreak species and the control, when the ANOVA indicated significant treatment effects at a probability level of $p < 0.1$.

RESULTS

Wind erosion

Eight, 12 and 11 erosion events occurred in each observation year between May and the beginning of August (Fig. 2). Erosion events in May 1991 were not measured at the 10-m distance due to missing instruments. During the strongest storm (1 June 1992) most of the samplers became overfilled or blocked and data could not be used. In each year the total amounts of captured soil were significantly reduced by windbreaks as well as by mulch application. Interactions between windbreaks and soil mulch were non-significant. Windbreak × distance and mulch × distance interactions, however, were significant as well as windbreak × event and mulch × event interactions. Averaged over all distances, total annual amounts of captured material in unsheltered plots without mulch attained 164 kg m^{-2} in 1991, 434 kg m^{-2} in 1992 and 395 kg m^{-2} in 1993. Without soil mulch, total annual soil fluxes within a 10-m distance from the windbreaks were significantly reduced during each storm in *A. gayanus* plots (by 6–55%) and by *B. rufescens* (by 47–77%), compared with the control (Fig. 3). The soil flux reductions by windbreaks at distances of 15 m were non-significant compared with the control.

A mulch application reduced overall soil flux by 51% in 1991, 49% in 1992 and 67% in 1993 across all windbreaks and the control. Significant effects of windbreaks on soil flux within mulched plots were found in two of the three years (Fig. 3). Total annual soil flux in the control plots with mulch decreased over distance in all years. The combination of the most effective shelter species, *B. rufescens*, with a soil mulch reduced erosion by 78% in 1991, 76% in 1992 and 84% in 1993, compared with unsheltered plots without mulch.

Chemical soil properties

All soil parameters, except sodium content in 1993, varied significantly with depth. In both observation years, there was no significant overall effect of the windbreak species on any of the soil chemical parameters, except for sodium content in 1991. There were significant effects of the distance from the windbreak on phosphorus and magnesium contents in 1991, and on potassium in both years.

The overall content of organic carbon was higher with both windbreak types than in the control in 1993, but this depended on soil depth. Up to a distance of 10 m, *B. rufescens* plots contained more organic carbon in the top layer than the control, but the effect was significant at a distance of 1 m only. Plots with *A. gayanus* had a higher organic carbon content than the control plots in the top layer and up to a distance of 3 m. In 1993, *B. rufescens* plots contained more total nitrogen than the control plots up to a distance of 10 m and down to a depth of 0.2 m, but the effect was significant in the top layer (0–0.1 m) and only at a distance of 1 m.

Phosphorus (P) contents showed considerable variability among treatments, and there was no consistent response to windbreak species or distance. The overall mean increased from 6.4 mg P kg^{-1} soil in 1991 to 8.8 mg in 1993. Potassium

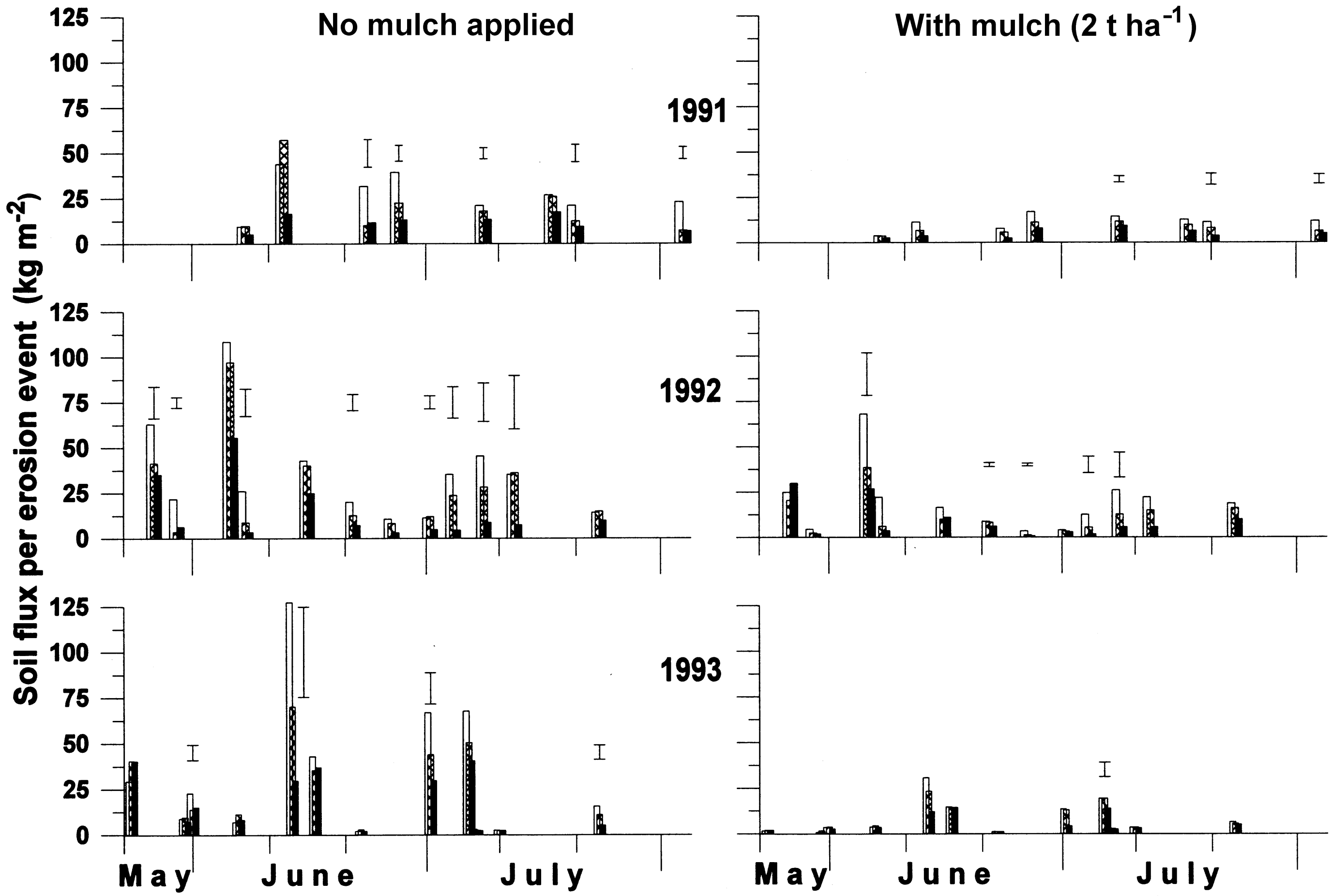

Fig. 2. Soil flux per erosion event at 0.1 m above the ground as affected by windbreaks (□, control without windbreak; ⊠, *Andropogon gayanus*; ■, *Bauhinia rufescens*) and mulching, 1991–93. Bars are averages from three distances from the windbreak. Erosion events during May 1991 and on 1 June 1992 not included. Error bars represent l.s.d. when ANOVA indicated significant ($p < 0.1$) treatment effects.

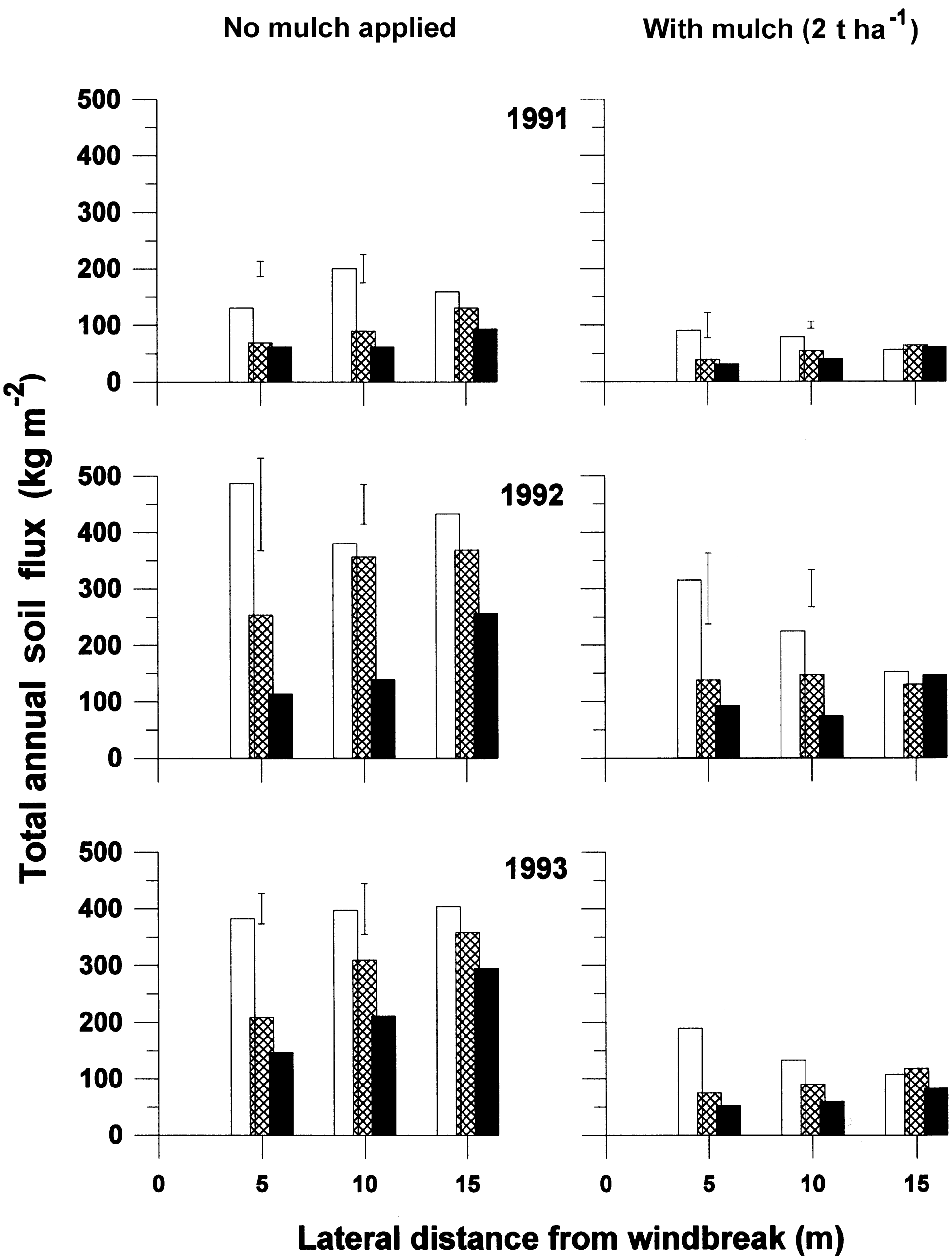

Fig. 3. Total annual soil flux at 0.1 m above the ground at three lateral distances from windbreaks (□, control; ⊠, *Andropogon gayanus*; ■, *Bauhinia rufescens*), with and without mulch application, 1991–93. Error bars represent l.s.d. when ANOVA indicated significant ($p < 0.1$) treatment effects.

contents in *B. rufescens* plots were higher than in the control at all but one measurement point, but the differences were non-significant. Calcium contents of the *B. rufescens* plots were higher than in the control in the top soil layer, at a depth of 1–2 m and up to a distance of 10 m. Plots with *A. gayanus* had a higher calcium content than the control in the deepest soil layer and at all distances. The magnesium content of the top soil layer was significantly increased in the *B. rufescens* plots compared with the control up to a distance of 3 m. The magnesium content was generally highest in the deepest soil layer.

Millet yields

The 1991 crop could not be harvested due to its poor establishment and growth in all treatments despite one resowing. This was caused by soil-borne pest damage and cold weather. The survival of millet in 1993 was generally higher than in 1992, but differences among windbreak species were small. Survival was highest in *A. nilotica* and lowest in *F. albida* plots. In 1993 the control plots had the lowest survival.

The 1993 grain yields were low due to damage by the millet head caterpillar (*Heliocheilus* (=*Raghuva*) *albipunctella*). No significant results were obtained in that year either for the measured yields or for calculated 'potential yields' using the cob : grain ratio of panicles from each sample. There was no significant effect of windbreaks on stover dry matter, grain yield or millet survival at harvest in 1992 and 1993 (Table 1). Mulch application gave highly significant results for all yield parameters in both observation years. No interaction between windbreak species and soil mulch was detected, except for millet survival in 1992. There was a significant overall year effect, and significant interactions between year and windbreak (Table 1). Orthogonal contrasts indicated differences among windbreak species and the control for stover dry matter and survival in 1993.

Plots with *F. albida* had the highest stover and grain production in 1992 and 1993 whereas the control showed the lowest total dry matter production, when means were averaged over both years. Millet in plots with *A. holosericea* rated second in total above-ground biomass. Stover and grain yields with all windbreak species except *F. albida* and *A. gayanus* were lower within the first 3 m from the hedge compared with distances of 4–9 m (Fig. 4). At distances greater than 3 m from the windbreaks, stover yields behind *F. albida* windbreaks remained nearly constant, whereas increases were found with the other species.

The mulch application increased survival significantly by 9%, stover production by 40% and grain yields by 23%, when averaged over both seasons. When mulched and unmulched subplots sheltered by the same windbreak were compared, it was found that the increase in stover yield due to mulching was higher on windbreak plots with low yields than on windbreak plots with higher yields. Examples of this were the *F. albida* plots, where stover yields with crop residue mulch were similar to those without mulch. No distance effects were found for millet survival.

Table 1. Millet survival (stands ha^{-1}), and stover and grain dry matter yield (kg ha^{-1}) as affected by year, windbreak species, and mulch application, 1992–1993.

	Millet survival†	Stover yield	Grain yield	Potential grain yield‡
Year				
1992	8600	1560	850	—
1993	9530	980	210	690
Year × windbreak species (1992)				
Faidherbia albida	8270	1970	1040	—
Acacia holosericea	8640	1750	1010	—
Azadirachta indica	8530	1670	890	—
Acacia nilotica	8990	1430	830	—
Andropogon gayanus	8780	1510	710	—
Bauhinia rufescens	n.a.	1460	810	—
Acacia senegal	8370	1170	650	—
Control without windbreak	n.a.	1530	830	—
Tukey's honest significant difference	n.s.	n.s.	n.s.	—
Year × windbreak species (1993)				
Faidherbia albida	9540	1380	270	1000
Acacia holosericea	9550	1080	170	710
Azadirachta indica	9540	850	210	730
Acacia nilotica	9650	1050	160	670
Andropogon gayanus	9530	900	210	560
Bauhinia rufescens	9540	800	220	550
Acacia senegal	9600	1140	260	880
Control without windbreak	9280	630	170	430
Tukey's honest significant difference	n.s.	660	n.s.	n.s.
Mulch application				
0 t ha^{-1}	8680	1060	470	—
2 t ha^{-1}	9450	1480	580	—
Year × mulch application (1992)				
0 t ha^{-1}	8200	1410	780	—
2 t ha^{-1}	9020	1710	910	—
Year × mulch application (1993)				
0 t ha^{-1}	9170	700	160	520
2 t ha^{-1}	9890	1250	250	860
ANOVA		Pr > F§		
Windbreak species	0.284	0.489	0.341	0.284 / 0.677
Mulch application	< 0.001	< 0.001	< 0.001	< 0.001 / < 0.001
Year	< 0.001	< 0.001	—	n.a.
Windbreak × mulch	0.573	0.547	0.752	0.035 / 0.866
Year × windbreak	0.002	0.008	—	n.a.
Year × mulch	0.001	0.330	—	n.a.
Year × windbreak × mulch	0.279	0.990	—	n.a.
Contrast: Windbreak *vs*. control	0.233	0.681	—	n.a.

†Due to missing values millet survival was analysed for each year separately.
‡Potential grain yield was calculated in the 1993 season because millet suffered severe damage; SAS code standing for the significance productivity value associated with the F value; n.s. = non-significant; n.a. = data not available.

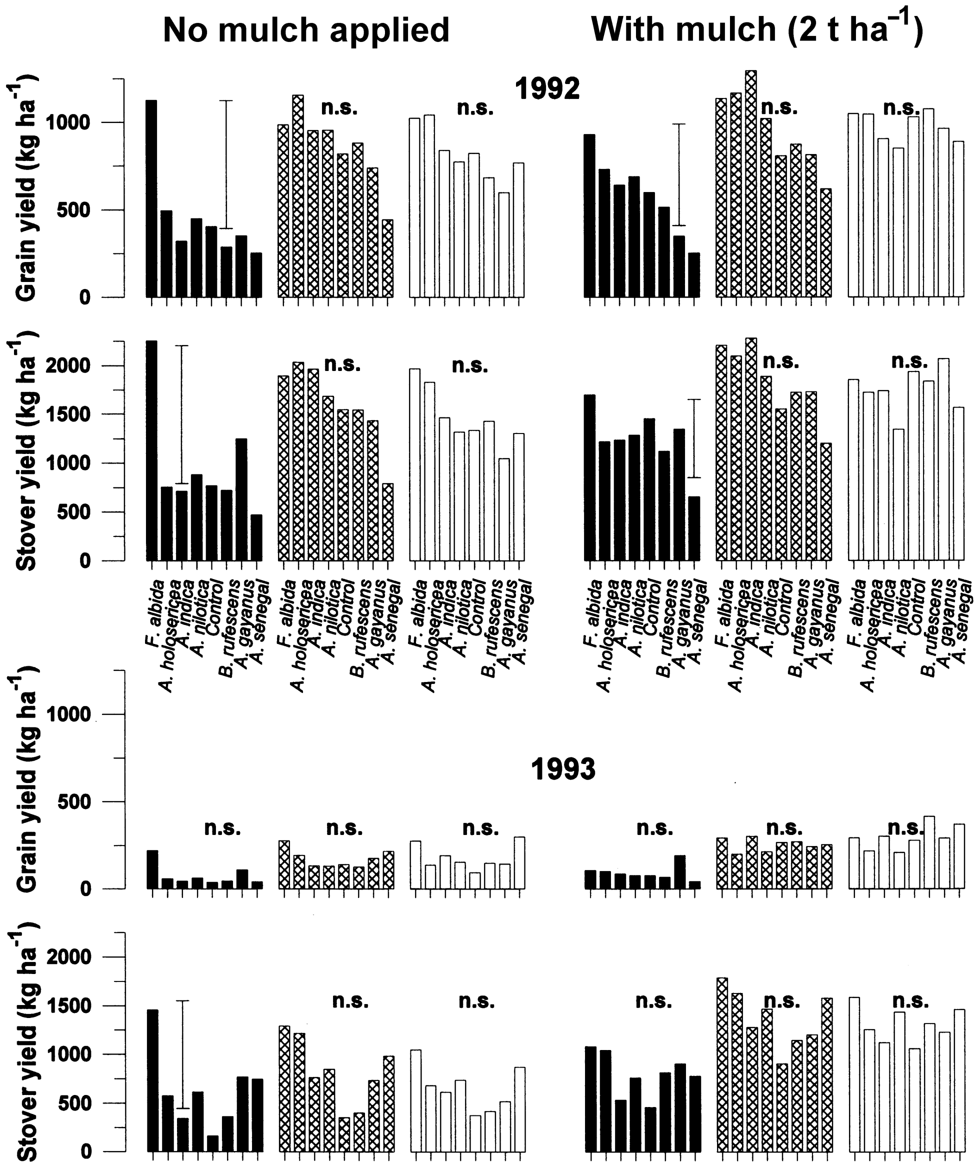

Fig. 4. Millet stover and grain yields as affected by windbreak species, lateral distance from windbreaks (■, 1–3 m; ⊠, 4–9 m; □, 10–20 m), and crop residue application, 1992–93. Error bars represent Tukey's honest significant difference (h.s.d.) when ANOVA indicated significant ($p < 0.1$) treatment effects; n.s. = non-significant.

DISCUSSION

Wind erosion

The annual totals of windblown material in this experiment were generally less than those measured in an adjacent trial at ISC. During 1991 and 1992, quantities of captured particles were around 1300 kg m^{-2} in a bare millet field and 700 kg m^{-2} in plots with 2000 kg stover mulch ha^{-1} (Michels *et al.*, 1995a). The lower amounts in the present trial may be due to differences in the landscape windward of the sites and a general wind speed reduction within the windbreak system. Despite an extremely low vegetative cover with millet plants during 1991, the average amounts of blown soil in 1991 were only half of those captured during 1992 or 1993.

The grass *A. gayanus* had a much lower windbreak porosity and thus higher sand fluxes than the local shrub *B. rufescens*. The porosity influenced drag and wind speed leeward of the windbreaks drastically. The effects of the monitored windbreaks on erosion were significant only up to a distance corresponding to five times the windbreak height. About ten times the windbreak height has been widely accepted as the protected area on the leeward side, but this is reduced when problem winds do not blow perpendicular to the windbreaks (Tibke, 1988).

The average 56% reduction in soil flux due to an application of 2 t stover mulch ha^{-1} was higher than what was measured in an adjacent field (46%) during the same years (Michels *et al.*, 1995a). This may be caused by the lower wind erosion forces and the lower soil flux in the windbreak trial. When barriers reduce wind speed close to the threshold velocity for soil transport, further obstacles like stover may decrease soil flux more than in a situation without any barriers. At distances of more than five times the windbreak height, the effects of barriers became less pronounced in cases when crop residue was applied.

As most Nigerien farmers cannot afford to use chemical fertilizers and at the same time reduce fallow periods, even small continuous nutrient losses by suspended soil particles from the top soil layer will reduce long-term soil productivity. There are, on the other hand, also important nutrient inputs by dust deposition (Herrmann, 1996) which were not measured in the present study.

Soil properties

In contrast with what might have been expected from the usually deep rooting systems of local tree species in semi-arid or arid regions, the effects of windbreaks on the chemical properties of the soil were mostly limited to a depth of 0–0.1 m when they occurred. Soil parameters showed high coefficients of variation, caused in part by the common micro-variability of soil properties in the region. Roots of a four-year-old dug-out *B. rufescens* shrub in our study were present to a depth of at least 3.7 m. Lateral roots at a depth of 2 m were found at a horizontal distance of more than 8 m. Vandenbeldt (1991) found roots of *F. albida* at a depth of 3.5 m at nine months after planting at ISC. The soil improving effect, particularly with *F. albida* trees, is often reported (Okorio, 1992; Depommier *et al.*, 1992; Kamara and Haque, 1992) but could not be confirmed in the present study.

Millet yields

Millet is very resistant against abrasion damage and sensitive to burial only in short distinct growth stages (Michels *et al.*, 1995b). This is consistent with the lack of measurable damage from wind erosion in the present study. Only the yield increases with *F. albida* compensated for the 11.7% area loss due to the barrier. This area occupied by the windbreak species may limit adoption by farmers when the species provides no economic benefit on its own as firewood or feed (Lamers, 1995). Higher windbreaks with a consequently wider protection area allow a wider spacing of the windbreaks, but higher trees may also increase the range for competition with the crop and modify the micro-climate (Brenner *et al*., 1995).

Positive effects of *F. albida* trees on grain yields are often reported (Vandenbeldt, 1992), but the reasons are not definitely understood (Geiger *et al*., 1992; Vandenbeldt and Williams, 1992; Schulze *et al*., 1991). In view of the high windbreak porosity and the low millet survival rates, the yield increases of millet bordered by *F. albida* could not be attributed to its protection against wind erosion. However, the effects of nutrient recycling from the decomposition of tree litter, and the absence of competition for water or nutrients during the rainy season because of its reverse phenology may explain the improved millet growth. Surveyed farmers around ISC ascribed the 'albida effect' in the first place to the fertilizing effect of manure, that is, that animals are attracted by the palatable fruits and leaves and subsequently deposit manure while grazing (Lamers, 1995). Animals did not have access to the experimental area in this trial and suggestions that the 'albida effect' might be caused by pre-existing 'islands' of fertility should have been counterbalanced by the use of a randomized experimental design in the present trial.

More leaf dry matter was produced by *A. holosericea* than by any other windbreak species (Lamers, 1995), a good indication that nutrient recycling of the litter – if not blown away – as well as high root turnover may have caused millet yield increases. Average millet yields were similar in neem shelters to those in the control but were lowest at a distance of 1–3 m from these windbreaks. Long and Persaud (1988) found reduced millet grain yields within a distance of twice the neem barrier height but, compared with the control, yields increased at distances further away from the windbreak. In Northern India, neem trees had no impact on yields of irrigated wheat, whereas *A. nilotica* trees delayed maturity and reduced yields of wheat by 40–60% (Puri and Bangarwa, 1992). The roots of *A. nilotica* tended to remain in the upper soil layers and there were possibly allelopathic effects from the leaf litter (Yadav *et al*., 1993).

Particularly low soil water content close to windbreaks were found by Brenner *et al*. (1995) and Banzhaf *et al*. (1992) at ISC during periods of overall low soil water content. This indicated a potential competition for water between trees and crops during drought spells. In this trial the differences in millet yields with different windbreak species were smaller in plots with mulch application than in plots without mulch which indicated that, in the presence of trees, the most limiting resources were compensated for by the mulch. Thus the crop residue had not only improved millet survival but may also have contributed important nutrients.

The present study did not focus on windbreak interactions with birds, pests or pathogens. There was, however, no evidence that millet growth, including the lost

1991 crop, was affected by pests or pathogens that were attracted by the windbreaks. Keeping birds off the ripening millet fields is local practice but there were indications that trees would increase the number of damaging birds.

In Sahelian farming systems mulching competes with the traditional uses for crop residues when land is limited (Lamers, 1995). Due to the high opportunity costs of crop residues, farmers may use them to increase their present income, but doing so depletes soil fertility. Given the long-term advantages of a crop residue mulch, an increase in crop residue production is essential. The use of external inputs, such as mineral fertilizers, could alleviate the demands on land and, consequently, overcultivation and soil degradation. An integrated windbreak–millet cropping system is most promising in regions that are more prone to wind erosion damage than the studied area or when the windbreak provides direct benefits to the farmers.

CONCLUSIONS

Shrubby windbreaks in the Southern Sahel decreased wind erosion up to distances of at least five times their height. Less porous windbreaks such as *B. rufescens* were more effective for wind erosion control than perennial grass barriers such as *A. gayanus*. Pearl millet survival rates did not depend on the existence of a windbreak. *F. albida* improved millet yields significantly for a horizontal distance up to ten times its height. Effects of *B. rufescens* and *A. gayanus* on chemical soil properties and millet yields were not significant.

Based on data from this study and the literature reviewed, it is becoming evident that the role of windbreaks for improving the livelihood of farmers in the Sahel is limited. Wind erosion and desertification may be reduced when species and management are appropriate, but in view of the only occasionally positive and sometimes negative impacts of windbreaks on agricultural production, recommendations for large windbreak plantations must be given with care. Mulching with organic material like crop residue, if available, can be an appropriate alternative for soil conservation.

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