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Wind Reduction Patterns Around Isolated Biomass for Wind-Erosion Control in a Desertified Area of Central Sudan

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Abstract: The aim of this study was to assess the effectiveness of sparse vegetation, feature common in arid zone, to reduce wind force (velocity) and hence protect the surface and regions downwind from drifting sand and their consequences. Respectively 4 (with heights h of 4, 3.2, 2 and 1.66 m), 2 (with h of 3 and 2.5 m) and 3 (with h of 1.04, 0.9 and 0.8 m) well established single biomass configurations of *Leptadenia pyrotechnica* trees, *Prosopis juliflora* trees and *Panicum turgidum* grass, were selected in the field. Solar powered cup anemometer wind measurements with a data logger system were taken at heights of 0.25 and 0.5 h, at distances 0.5 and 1 h, at four sides of the tree in the prevailing wind direction and perpendicular to it, and additionally at 2, 4 and 6 h windward and leeward. The protection effectiveness of the biomass was calculated as a wind reduction ratio and in terms of objects protection, which was evaluated using the dimensionless protection index (f). The study showed that windward protection provided by *Leptadenia* and *Prosopis* at level 0.25h and distance 0.5 h was similar, with a wind reduction ratio R0.8, while *Panicum* showed comparably higher R-values. Even at the 0.5 h level, *Panicum* showed an R of 0.65 at 0.5 h distance. Leeward, at 0.25 h level differences were small, R increasing from 0.6/0.7 to 0.8/1 with distance, *Leptadenia* protecting best. At higher level (0.5 h) at distances 0.5 and 1 h *Prosopis* gave better protection than the other two at distances 0.5, 1 and 2 h. The research is an example of simple experimental work under difficult environmental conditions in Africa. It was part of studies in which additional attention was paid to quantification aspects under such conditions as well as to the problems it helped solve in the African societies concerned as agrometeorological services.

Key words: Arid, desertification, *Leptadenia pyrotechnica*, *Panicum turgidum*, *Prosopis juliflora*, sparse

INTRODUCTION

Wind is defined as displacement of air relative to the surface. The differences in atmospheric pressure, which are caused by variation in temperature distribution, are the main causes of wind (WMO, 1989). Wind is an erosive agent. When it blows strong enough over erodible surface, particles start to move. Depending on the wind structure (turbulence, eddies) and the surface structure as well as on the sizes of surface grains, the surface reacts. On immobile parts of the surface, grains only role or bounce. On a surface containing sand they give part of their momentum to other particles, causing them to creep or, when they are smaller, to saltate. When they are very small, particles get into suspension (Bagnold, 1941; Chepil and Woodruff, 1963; Wilson and Cook, 1980; Mohammed *et al.*, 1995a, 1999). Wind engineering is the rational treatment of the interactions between wind in the atmospheric boundary layer and man and his works on the surface of the earth (Wisse and Stigter, 2007).

During saltation the wind energy depletes, and as a result two wind profiles can be distinguished. There will be one within the layer of saltation, modified by the saltation, and there will be a second above the saltation layer, behaving as if no saltation occurs, but the latter wind profile is displaced upwards. The effect of the saltation on the air flow is similar to that of solid roughness (Owen, 1964; Gerety, 1985; Watson, 1989). To mitigate the effect of wind action on soil particles, they have to be stabilized. The stabilization of soil particles

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can be induced by trapping or enforcing moving particles to settle by producing a rough surface. This may be done by covering the surface with any material that will suppress erosion such as mulch, but a natural vegetation cover is the most effective one (e.g., Stigter *et al.*, 2002), also because it can't be blown off (Stigter *et al.*, 2005a).

The effectiveness of sparse vegetation to reduce wind force and protect the surface, a situation more common in dry regions, was thoroughly considered by Nichkling and Wolfe (1993). The effectiveness of a biological barrier to reduce erosion is determined by wind speed and duration, erodibility of the surface, and biomass distribution (Chepil and Woodruff, 1963; Lyles, 1988; Mohammed *et al.*, 1995b; 1996a; 1999). For more theoretical and quantitative studies on wind and air movement near trees and their consequences consult Spaan and Stigter, 1991; Mohammed *et al.*, 1996b; Stigter *et al.*, 1997; Kainkwa and Stigter, 2000; Stigter *et al.*, 2000; Onyewotu *et al.*, 2004).

Simple quantification can be extremely helpful in understanding essential phenomena in agricultural production, also under the difficult environmental and field conditions of Africa (e.g., Stigter and Darnhofer, 1989; Stigter *et al.*, 1989; Mungai *et al.*, 2000). Measurements of wind speed and observation of consequences of air moving around and between trees and shelterbelts has always been a special field of our attention. Because also simple quantification can assist very well in explanations of related phenomena in forests and for conditions of non-forest trees (e.g., Coulson and Stigter, 1989; Geiger *et al.*, 1995 (in honour of his pioneering work on these matters since the 1920s); Kainkwa and Stigter, 2000; Stigter *et al.*, 2000; 2005b). Such quantification can also very well assist in designs of protective systems (Stigter, 1994; 2010).

As a consequence of earlier work described shortly below, it appeared necessary to find ways of protecting large tracks of completely or nearly completely desertified land in Central Sudan by a minimum of new vegetation. The measurements reported on here were established to determine the effectiveness of reducing wind by isolated biomass configurations that had been determined as best establishable under the local conditions (Al-Amin *et al.*, 2006). Already early in our African work the importance of scattered trees in wind protection in general and wind erosion reduction in particular was recognized (Kainkwa and Stigter, 1994; Stigter *et al.*, 1997) and wind problems continued to be in our research fronts in four African countries (Stigter *et al.*, 2002, 2003; Stigter, 2010).

The work reported on here was initiated after studies of wind reduction and sand settlement by a shelterbelt established for that purpose near the Gezira irrigation scheme in central Sudan (Mohammed *et al.*, 1995a, 1995b). Quantification of sand flow increased our understanding of the large scale erosion occurring in those areas (Mohammed *et al.*, 1996b) and the land degradation threatening invaded areas (Stigter *et al.*, 2005a).Wind measurements in these studies had contributed to an understanding of wind behaviour in the region and near the belt (Mohammed *et al.*, 1999; Stigter *et al.*, 2000; 2005c). This could also be used in design proposals for such shelterbelts (Mohammed *et al.*, 1996a). The designs of possible contributions to solutions of wind erosion protection must be seen as agrometeorological services to farmers in the endangered areas (Stigter *et al.*, 2004; 2005d; Stigter, 2007; Stigter and Al-Amin, 2007; Stigter, 2010). Generally, the study assessed the effectiveness of sparse scattered natural vegetation, feature common in arid zone, to reduce wind force, and hence protect the regions downwind from drifting sand and their consequences. Therefore, the study aimed to measure wind velocity around each biomass and monitored its capability to reduce wind velocity and suppress sand movement, and hence deposits its load (sand).

MATERIALS AND METHODS

The study area is located between latitudes 14º and 15ºN and longitude 32º and 33ºE, in Central Sudan. It consisted of a vast bare soil (about 5500 Km^2) without obstacles, with some scattered sand dunes and sand sheet with hummocks around the area. The area is subject to blowing sand from south and southwest during summer time and from north and northeast during winter.

Wind field measurements around biomass: Some years ago our work on the establishment of trees under the completely desertified conditions of the environment under study was published (Al-Amin *et al.*, 2006). Our choice of trees for the results presented here was at that time based on those results. Well established single biomass configurations were selected in the field: *Leptadenia pyrotechnica* trees of 4, 3.2, 2 and 1.66 m high, *Prosopis juliflora* trees of 3 and 2.5 m high and *Panicum turgidum* grass of 1.04, 0.9 and 0.8 m high. The trees/grasses had different height, biomass distribution, shape, porosity, and crown diameter. Such differences existed between different species as well as within the same species.

Also for developing countries use of developments in agrometeorological data taking (Hubbard, 1994; Motha, 2010) can be recommended, particularly with external funding of educational projects (Stigter *et al.*, 1998). An example of this approach is in our programmes that needed extensive wind measurements (Stigter *et al.*, 2005b). Calibrated electrical cup anemometers designed and manufactured at

Table 1: Biomass distribution and general description of trees/grasses used for the first and second

Tree	Height (m)	Species	General description
1.1	4	*Leptadania*	Had appreciable width (2 m). Permeability was low in the middle, increasing in a circle that touches the surface.
1.2	3.2	*Leptadania*	Its biomass was hemispherical in shape in the upper half and cylindrical in the lower half with low permeability less than 20%, increasing towards the surface and decreasing outwards.
1.3	2.00	*Leptadania*	Highly open at bottom, because the biomass was sloping from the stem upwards.
1.4	1.66	*Leptadania*	Had a biomass of a V-shape and was highly permeable.
2.1	3.00	*Prosopis*	Semi-circular biomass distribution on a highly asymmetrically situated stem, denser in the lower more than half and rather permeable more upward
2.2	2.50	*Prosopis*	Semi-circular biomass distribution on a highly asymmetrically situated stem, dense near the surface till halfway upwards and rather permeable higher upward
3.1	1.04	*Panicum*	Multi stem, dense near the surface, biomass decreasing upwards (rather permeable).
3.2	0.90	*Panicum*	With a width of about 0.4 m, rather dense
3.3	0.80	*Panicum*	Multi stem, very dense near the surface, biomass decreasing upwards

Table 2: Wind speeds (W_o) in *the* open and wind reduction ratios (R) around *Leptadania Pyrotechnica* (4 m high, tree 1.1) of the first run

	W_o and R at level 0.25 h distance						W_o and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	4.8	5.7	4.9	---	---	Open	7.4	5.5	5.1	---	---
R-Wind	0.82	0.86	0.93	---	---	R-Wind	0.81	1.02	0.97	---	---
Open	4.8	5.7	4.9	4.9	4.9	Open	7.4	5.5	5.1	5.1	5.1
R-Lee	0.11	0.16	0.52	0.64	0.86	R-Lee	0.18	0.24	0.52	0.66	0.9
East	0.95	0.95	---	---	---	East	---	0.99	---	---	---
West	1.02	0.91	---	----	---	West	0.95	1.08	---	---	---

Open = wind speed in the open (W_o); R-Wind = wind reduction ratio windward; R-Lee = wind reduction ratio leeward; East = wind reduction ratio east of the tree; West = wind reduction ratio west of the tree

Wageningen University, the Netherlands, and a solar panel cum battery operated CR10(Campbell Scientific) programmable data logger were used. Experimental approaches with such systems were reviewed for four African countries (Stigter *et al.*, 2005b). These anemometers have stalling speeds of 0.1-0.3 per ms and ±3% accuracy within the measuring range of 1-15 per ms. They were in this case specially protected against sand blast. The cups were fitted on cylindrical arms of 0.9 m long to avoid mast influence.

Two runs of wind speed profile readings were taken around selected trees/grasses, one with northern and north-western prevailing winds (March-April 1995). Table 1, *Leptadenia pyrotechnica* of 4, 3.2 and 2 m high (trees 1.1, 1.2 and 1.3), *Prosopis juliflora* of 3 and 2.5 m high (trees 2.1 and 2.2) and *Panicum turgidum* of 1.04 and 0.9 m high (grass 3.1 and 3.2). The second run was carried out during southern wind (during June-July 1996). The measurements were around one specimen from each species (since most of the selected specimens were removed by people in need of firewood during the course of the measurements). It was around *Leptadenia pyrotechnica* of 1.66 m (tree 1.4), *Prosopis juliflora* of 3 m high (tree 2.2) and *Panicum turgidum* of 0.8 m (grass 3.3). Sometimes during the measurements of the second run the wind direction changed, e.g., from south to southwest and even sometimes to totally opposite direction i.e. north.

Wind protection around single trees was evaluated around the tree parallel and perpendicular to the incident wind field. This was done at two heights windward and leeward from the tree in the middle of the tree, and on both sides of the tree. Four masts were used simultaneously, as can be seen from the Table 2 to 9, with each mast having two anemometers at two different levels, i.e., 0.25 and 0.5 h, where h stands for the biomass height. Because wind reduction is measured, not all positions around the biomass have to be measured simultaneously, Another mast was used with three anemometers at levels 0.25, 0.5 and 1 h, located in an open area as a control. Twelve samples of 10 min averaged wind speeds (m/s) for all levels and distances for each biomass configuration were recorded, leeward, windward and in the open for the two runs.

Wind reduction ratio (R): The protection effectiveness of the biomass was calculated as a wind reduction ratio R (e.g., Stigter, 1994) of the wind speeds (two hours averages) as:

$$R = W_t \ / W_o$$

where,

W_t is the wind speed at any level for any distance from the tree,

W_o is the wind speed at the same level in the open.

RESULTS AND DISCUSSION

Wind reduction ratio for the first run: Table 1 displays the biomass distribution and general description of

Table 3: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Leptadania Pyrotechnica* (3.2 m high, tree 1.2) of the first run

	Wo and R at level 0.25 h distance						Wo and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	4.8	5.2	4.9	---	---	Open	7.4	7.4	8.4	---	---
R-Wind	0.79	0.88	0.78	---	---	R-Wind	0.87	0.88	0.93	---	---
Open	4.8	5.2	5.2	5.2	5.6	Open	4.8	5.2	5.7	6.0	6.0
R-Lee	0.12	0.24	0.96	0.99	1.08	R-Lee	0.21	0.28	1.01	1.07	1.08
East	0.92	0.97	---	---	---	East	1.05	0.98	---	---	---
West	0.93	1.0	---	---	---	West	0.97	1.01	---	---	---

Open= wind speed in the open (W_o); R-Wind = wind reduction ratio windward; R-Lee = wind reduction ratio leeward; East = wind reduction ratio east of the tree; West = wind reduction ratio west of the tree

Table 4: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Leptadania Pyrotechnica* (2 m high, tree 1.3) of the first run

	W_o and R at level 0.25 h distance						W_o and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	5.6	6.9	6.1	---	---	Open	6.1	7.4	6.6	---	---
R-Wind	0.86	0.88	0.9	---	---	R-Wind	0.88	0.87	0.91	---	---
Open	5.6	6.9	6.1	6.1	6.1	Open	6.1	7.4	6.5	6.5	6.5
R-Lee	0.5	0.54	0.56	0.79	0.88	R-Lee	0.56	0.57	0.57	0.83	0.87
East	0.93	0.93	---	---	---	East	0.92	0.94	---	---	---
West	0.98	0.92	---	---	---	West	0.99	0.92	---	---	---

Open = wind speed at open (W_o); R-Wind = wind reduction ratio at the windward; R-Lee = wind reduction ratio at the leeward; East = wind reduction ratio east to the tree; West = wind reduction ratio west to the tree

Table 5: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Prosopis* (3 m high, tree 2.1), of the first run

	W_o and R at level 0.25 h distance						W_o and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	6.2	5.8	4.9	---	---	Open	6.6	6.1	5.1	---	---
R-Wind	0.94	0.96	0.96	---	---	R-Wind	0.97	0.97	0.99	---	---
Open	6.2	5.8	4.9	4.9	4.9	Open	6.6	6.1	5.1	5.1	5.1
R-Lee	0.74	0.75	0.85	0.91	0.93	R-Lee	0.8	0.78	0.88	0.92	0.95
East	0.98	0.98	---	---	---	East	0.99	0.98	---	---	---
West	1.0	1.0	---	---	---	West	0.92	1	---	---	---

Open = wind speed at open (W_o); R-Wind = wind reduction ratio at the windward; R-Lee = wind reduction ratio at the leeward; East = wind reduction ratio east to the tree; West = wind reduction ratio west to the tree

Table 6: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Prosopis* (2.5 m high, tree 2.2) of the first run

	W_o and R at level 0.25 h distance						W_o and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	4.1	2.7	3.7	---	---	Open	4.4	2.9	3.7	---	---
R-Wind	0.80	0.94	1.02	---	---	R-Wind	0.82	0.94	0.93	---	---
Open	4.1	2.7	3.7	3.7	3.7	Open	4.1	5.6	3.7	3.9	3.9
R-Lee	0.59	0.63	1.00	0.97	0.91	R-Lee	0.59	0.71	0.97	0.98	0.98
East	0.64	0.85	---	---	---	East	0.94	0.87	---	---	---
West	0.77	0.91	---	---	---	West	0.85	0.85	---	---	---

Open = wind speed in the open (W_o); R-Wind = wind reduction ratio windward; R-Lee = wind reduction ratio leeward; East = wind reduction ratio east of the tree; West = wind reduction ratio west of the tree

trees/bushes used in the first and second runs. Actual measured wind, for the first run, in the open (W_O) and calculated reduction ratio (R) values are given in the Table 2-4 for *Leptadenia pyrotechnica* (trees 1.1 till 1.3), Table 5 and 6 for *Prosopis juliflora* (trees 2.1 and 2.2) and Table 7 and 8 for *Panicum turgidum* (grass 3.1 and 3.2).

The windward protection of tree 1.1 at a height of 0.25 h was rather low, 0.82, 0.86 at distances 0.5 and 1 h, respectively, while this effect faded away at 2 h where R = 0.93. Leeward, at a height of 0.25 h, this tree has the highest protection in comparison to the other trees, with R-values of 0.11, 0.16, 0.52, 0.64 and 0.86 at distances 0.5, 1, 2, 4 and 6 h, respectively. With few exceptions, reduction ratios R at level 0.5 h are slightly higher than those at level 0.25 h but they have the same trends (Table 2).

Tree 1.2 had little effect on the windward wind pattern, where R was around 0.9, with the exception of 0.5 and 2 h at the 0.25 h level, where it was close to 0.8. This tree looks similar to tree 1.1, but with a relatively smaller crown diameter and highly permeable at the (very) surface (Table 1). This feature very clearly explains the low values of R, of 0.12 and 0.24 at 0.5 and 1 h, at

Table 7: Wind speeds (W_o) in the open and wind reduction ratios (R) around *panicu*m (1.04 m high, tree 3.1) of the first run

	W_o and R at level 0.25 h distance						W_o and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	7.7	6.5	5.1	---	---	Open	7.9	6.7	5.0	---	---
R-Wind	0.78	0.86	0.97	---	---	R-Wind	0.95	0.98	1.02	---	---
Open	7.7	6.5	5.1	5.1	5.1	Open	7.9	6.7	5.0	5.2	5.2
R-Lee	0.28	0.53	0.66	0.85	0.91	R-Lee	0.55	0.82	0.83	0.87	0.90
East	1.00	1.02	---	---	---	East	0.99	1.04	---	---	---
West	1.00	1.03	---	---	---	West	1.02	1.04	---	---	---

Open = wind speed at open (W_o); R-Wind = wind reduction ratio at the windward; R-Lee = wind reduction ratio at the leeward; East = wind reduction ratio east to the tree; West = wind reduction ratio west to the tree

Table 8: Wind speeds (W_o) in the open and wind reduction ratios (R) around *panicu*m (0.9 m high, tree 3.2), of the first run

	W_o and R at level 0.25 h distance						W_o and R at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	7.2	6.7	5.3	---	---	Open	6.8	6.4	5.0	---	---
R-Wind	0.89	0.90	0.96	---	---	R-Wind	0.94	0.99	0.97	---	---
Open	6.8	6.4	5.0	5.0	5.0	Open	7.2	6.8	5.3	5.3	5.3
R-Lee	0.20	0.15	0.52	0.81	0.88	R-Lee	0.61	0.40	0.60	0.81	0.88
East	0.93	0.98	---	---	---	East	0.97	0.99	---	---	---
West	1.05	0.96	---	---	---	West	1.04	0.99	---	---	---

Open = wind speed in the open (W_o); R-Wind = wind reduction ratio windward; R-Lee = wind reduction ratio leeward; East = wind reduction ratio east of the tree; West = wind reduction ratio west of the tree

Table 9: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Leptadania Pyrotechnica* (1.66 high, tree 1.4), of the second run

	wind speed reduction ratio at level 0.25 h distance						wind speed reduction ratio at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	5.6	6.9	6.1	---	---	Open	6.1	7.4	6.6	---	---
R-wind	0.78	1	0.99	---	---	R-Wind	1	0.93	0.98	---	---
Open	5.6	6.9	6.1	6.1	6.1	Open	6.1	7.4	6.5	56.	6.6
R-Lee	0.57	0.68	0.78	0.82	0.87	R-Lee	0.69	0.76	0.86	0.88	0.89
East	1	0.92	---	---	---	East	1.1	1	---	---	---
West	1	0.85	---	---	---	West	1.1	0.89	---	---	---

Open = wind speed in the open (W_o); R-Wind = wind reduction ratio windward; R-Lee = wind reduction ratio leeward; East = wind reduction ratio east of the tree; West = wind reduction ratio west of the tree

Table 10: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Prosopis* (3 m high, tree 2.1) of the second run

	wind speed reduction ratio at level 0.25 h distance						wind speed reduction ratio at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	8.4	5.2	5.2	---	---	Open	8.9	8.9	8.3	---	---
R-Wind	0.79	0.82	0.87	---	---	R-Wind	0.86	0.89	0.93	---	---
Open	8.4	5.2	5.2	5.2	5.6	Open	8.9	5.6	5.6	5.6	5.6
R-Lee	0.67	0.69	0.81	0.88	0.97	R-Lee	0.53	0.64	0.72	1	1
East	0.97	0.99	---	---	---	East	1	1	---	---	---
West	0.87	0.91	---	---	---	West	0.93	1	---	---	---

Open = wind speed at open (W_o); R-Wind = wind reduction ratio at the windward; R-Lee = wind reduction ratio at the leeward; East = wind reduction ratio east to the tree; West = wind reduction ratio west to the tree

Table 11: Wind speeds (W_o) in the open and wind reduction ratios (R) around *Panicu*m (0.8 m high, tree 3.3), of the second run

	wind speed reduction ratio at level 0.25 h distance						wind speed reduction ratio at level 0.5 h distance				
	0.5 h	1 h	2 h	4 h	6 h		0.5 h	1 h	2 h	4 h	6 h
Open	7.9	5.6	3.8	---	---	Open	8.2	6.0	4.0	---	---
R-Wind	0.94	0.86	1	---	---	R-Wind	0.65	0.92	1	---	---
Open	7.9	5.6	3.7	3.7	3.7	Open	8.2	6.0	4.0	3.9	4.0
R-Lee	0.68	0.76	1	1	1	R-Lee	0.69	0.87	1	1	1
East	0.99	0.64	---	---	---	East	1	0.8	---	---	---
West	0.94	0.81	---	---	---	West	1	0.88	---	---	---

Open = wind speed at open (W_o); R-Wind = wind reduction ratio at the windward; R-Lee = wind reduction ratio at the leeward; East = wind reduction ratio east to the tree; West = wind reduction ratio west to the tree

level 0.25 h and of 0.21 and 0.28 at level 0.5 h, but much higher values (of even above 1) beyond that distance (Table 3).

The tunnel for wind near the surface results in low and even negative protection provided by this tree beyond 1h. The point at which the main speed in the open was regained, which may be called the point of reattachment, was between distances 1 and 2 h. This is due to the biomass distribution. In case of tree 1.2, the wind was lifted over the tree, as the density of the tree increased upwards and no wind was forced along the sides of the tree at the distances covered (at 0.25 h average R<1 at both sides). The reattachment point for tree 1.1 of 4 m high was further away (beyond 6h). Also for the latter tree there was no wind forced along the tree at 0.25 h (with R<1). At 0.5h R was just again close to 1 for both trees.

The biomass distribution and the relatively high permeability of tree 1.3 (Table 1) explain the R values depicted in Table 3. Windward this tree was providing little protection in roughly the same manner as the other two trees above, with somewhat closer agreement between trees 1.1 and 1.2 at 0.25 h and between 1.2 and 1.3 at 0.5 h. Leeward 1.3 was generally appreciably less protective than 1.2 at distances closer than 2 h at both heights, but 1.1 was generally most protective, still in line with the related permeability.

While windward there was again little protection, leeward R for tree 1.3 was rather high, so the protection low, compared to trees 1.2 and 1.1 for 0.5 and 1 h, but for level 0.25 h it was only slightly higher than for 1.1 beyond 1h while substantially lower than for 1.2 (Table 4). At level 0.5 h the picture was variable beyond 1 h. At 2 h R was substantially higher for tree No.1.2, at 4h the value for tree No. 1.3 was substantially higher than for tree No.1.1 but lower than for tree No. 1.2 for reasons earlier given.

For *Prosopis juliflora* Table 5 and 6 show again no or little protection windward, with $R^3$0.94 at 2, 1 and 0.5 h at both levels for tree 2.1. Something similar was true for tree 2.2, at level 0.25 h, with $R^3$0.93 at 2 h and 1h, but here R»0.8 at 0.5 h. Leeward R at 0.5 and 1 h was clearly lower than windward and lower for tree 2.2 at both levels. It was providing better protection at these distances relative to tree 2.1, since the latter was highly permeable higher upward (Table 1). Compared to *Leptadenia pyrotechnica* described previously, *Prosopis* sp. had windward and leeward higher R (lower protection), again due to the permeability distributions of the latter.

The two different bushes of *Panicum* turgidum grass (1.04 and 0.9 m high, 3.1 and 3.2, respectively) did not show very great differences in their sizes and shapes but they were sufficiently different to show some differences in the R-patterns (Table 1). The protection provided by this species (Table 7 and 8) windward is again low, with a lowest value of 0.78 for grass 3.1 at distance 0.5 h for the 0.25 h level, very comparable to the other species tested. Leeward, both grasses showed at 0.5 h a lower value of R (higher protection) for level 0.25 h compared to level 0.5 h. The velocity of the wind leeward of grass 3.1 was reduced at level 0.25 h with an R = 0.28 compared to R = 0.55 at level 0.5 h, while for grass 3.2 these values were 0.2 and 0.61, respectively. At 0.25 h, R gradually increased away from the stands with exception of 1h from grass 3.2, while at 0.5 h level R remained considerably increased, meaning a low protection, for grass 3.1. For grass 3.2, there was at this height again typically biomass distribution related anomaly at 1 h while at 2 h R was still relatively low. For both tree the high density at the base of these bushes can explain the high protection at level 0.25 h relative to level 0.5 h, for the distances up till 1 h. The anomalies are explained by this as well.

Wind reduction ratio for the second run: If the Table 5 and 10 are compared, the same tree 2.1 in the two different runs, it may be observed that they are not sufficiently similar to be comparable as if for one and the same run. The permeability distribution in the direction of the wind must have been too different for such a comparison to hold. That is why the two runs are not compared.

The measurements in Table 9 and 10, around *Leptadenia* tree 1.4 and *Prosopis* tree 2.1, windward showed at 0.5 h for level 0.25 h similar R values (0.78 and 0.79, respectively). These values for both trees increased with distance from the tree, indicating low protection where at 1 and 2 h both trees had high R values (0.82 and 0.87 for *Prosopis* 2.1 compared to 1 and 0.99 for *Leptadenia* 1.4), respectively. Leeward at level 0.25 h *Leptadenia* 1.4 showed better protection compared to *Prosopis* 2.1 with lower R values for *Leptadenia* than for *Prosopis* 2.1 at all distances. At level 0.5 h the scenario is opposite, *Prosopis* 2.1 showing better protection than *Leptadenia* 1.4 at distances 0.5, 1 and 2 h. At distances further than 2 h, *Leptadenia* 1.4 showed very low protection with R = 0.88 and 0.89 for 4 and 6 h respectively, but *Prosopis* 2.1 did not affect the wind at these distances at all. In the case of *Panicum* grass 3.3, at both levels at distance 0.5 h R-values did not differ that much while at distance 1 h, level 0.25 h had a somewhat lower value of R than level 0.5 h. Beyond 1h no protection was provided at both levels (Table 11). Leeward the wind reduction expressed as a fraction of the height was generally lower around the Panicum grass in comparison with the other species during this run.

CONCLUSION

These experiments on wind speed patterns around selected trees had been mainly set up to determine suitability of existing vegetation to protect the area from drifting sand and wind erosion through sand settlement (Al-Amin *et al.*, 2005). An analysis of those patterns could assist in designing an ideal tree for such purpose, as was done by Mohammed *et al.* (1996a) in designing shelterbelts to reduce wind speed and capture moving sand. Such a design could in principle be compared with potential exotic species, but for large areas this would lead away from local reality.

The results show that *Leptadenia pyrotechnica* species provide relatively good protection against consequences from erosion. They are present in good concentration in certain areas. *Prosopis juliflora* species are protecting the area well, but they are unfortunately targeted by a government policy of complete eradication because they are considered too aggressive. However, this could well be an advantage under our conditions. *Panicum turgidum* appeared to have high efficiency of collecting and capturing moving sand relative to their small sizes, in particular when found in association. Therefore, from our results the protection of all existing vegetation, regeneration of local vegetation and use of all means to increase the numbers of scattered trees and grass stands for protection, with functional application of laws and regulations, are recommended.

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REFERENCES

Al-Amin, N.K.N, C.J. Stigter, M.A.M. Elagab and M.B. Hussein, 2005. Combating desert encroachment by guiding people, wind and sand. J. Agr. Meteorol., (Japan), 60: 349-352.

Al-Amin, N.K.N., C.J. Stigter and A.E. Mohammed, 2006. Establishment of trees for sand settlement in a completely desertified environment. Arid Land Res. Manage., 20: 309-327.

Bagnold, A.R., 1941. The Physics of Blown Sand and Desert Dunes. Methuen and Co., London, pp: 143.

Chepil, W.S. and N.P. Woodruff, 1963. The physics of wind erosion and its control. Adv. Agron., 15: 211-301.

Coulson, C.L. and C.J. Stigter, 1989. Appropriateness of instrumentation in agroforestry research in developing countries. In: Reifsnyder, W.E. and T. Darnhofer (Eds.), Meteorology and Agroforestry. Proceedings of an ICRAF/WMO/UNEP Workshop on Application of Meteorology in Agroforestry Systems Planning and Management, Nairobi, Kenya. ICRAF, Nairobi, pp: 305-314.

Geiger, R., R.H. Aron and P. Todhunter, 1995. The Climate Near the Ground. 5th Edn., Geiger's Original. Vieweg, Braunschweig, pp: 528.

Gerety, K.M., 1985. Problem with Determination of U, from Wind-Velocity Profiles Measured in Experiments with Saltation. In: Bandoruff-Nielsen, O.E., J.T. Moller and B.B. Willetts (Eds.), Proceedings of the International Workshop on the Physics of Blown Sand. Department of Theoretical Statistics, Aarhus, pp: 371-300.

Hubbard, K. G., 1994. Measurement systems for agricultural meteorology. In: J.F. Griffiths (Ed.), Handbook of Agricultural Meteorology. Oxford University Press, New York and Oxford, pp: 76-79.

Kainkwa, R.M.R. and C.J. Stigter, 1994. Wind Reduction Downwind from a Savanna Woodland Edge. Neth. J. Agric. Sc., 42: 145-157.

Kainkwa, R.M.R. and C.J. Stigter, 2000. Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters I. Validation of the square-root dependence on wind speed. Intern. Agrophys, 14: 279-289.

Lyles, L., 1988. Basic wind erosion processes. Agric. Ecosyst. Environ., 22/23: 91-101.

Mohammed, A.E., C.J. Stigter and H.S. Adam, 1995a. Moving sand and its consequences in and near a severely desertified environment and a protective shelterbelt. Arid Soil Res. Rehab. 9: 423-435.

Mohammed, A.E., C.J. Stigter and H.S. Adam, 1995b. Holding back the desert: A eucalyptus shelterbelt in central Sudan. Agroforestry Today, 7 (1): 4-6.

Mohammed, A.E., C.J. Stigter and H.S. Adam, 1996a. On shelterbelt design for combating sand invasion. Agric. Ecosyst. Environ., 57: 81-90.

Mohammed, A.E., O.D. van de Veer, H.J. Oldenziel and C.J. Stigter, 1996b. Wind tunnel and field testing of a simple sand catcher for sampling inhomogeneously saltating sand in desertified environments. Sedimentology, 43: 497-503.

Mohammed, A.E., C.J. Stigter and H.S. Adam, 1999. Wind regimes windward of a shelterbelt protecting gravity irrigated crop land from moving sand in the Gezira Scheme (Sudan). Theor. Appl. Climatol., 62: 221-231.

Motha, R.P., 2010. Meteorological Data to Support Farming Needs. Chap. 6, In: Stigter, K. (Ed.), Applied Agrometeorology. Springer, Heidelberg etc., (In press).

Mungai, D.N., C.J. Stigter, C.L. Coulson, J.K. Ng'ang'a, 2000. Simply obtained global radiation, soil temperature and soil moisture in an alley cropping system in semi-arid Kenya. Theor. Appl. Climatol., 65: 63-78.

Nichkling, S.G. and A. Wolfe, 1993. The protective role of sparse vegetation in wind erosion. Progr. Phys. Geogr., 17: 50-68.

Onyewotu, L.O.Z., C.J. Stigter, E.O. Oladipo and J.J. Owonubi, 2004. Air movement and its consequences around a multiple shelterbelt system under advective conditions in semi-arid Northern Nigeria. Theor. Appl. Climatol., 79: 255-262.

Owen, P.R., 1964. Saltation of uniform grains in air. J. Fluid Mech., 20: 225-242.

Spaan, W.P. and C.J. Stigter, 1991. Measuring wind erosion with simple devices: A synopsis. Mitteil. Deutsche Bodenkundl. Gesellsch, 65: 51-56.

Stigter, C.J., 1994. Management and Manipulation of Microclimate. In: Griffiths, J.F. (Ed.), Handbook of Agricultural Meteorology. Oxford University Press, New York and Oxford, pp: 273-284.

Stigter, C.J., 2007. From basic agrometeorological science to agrometeorological services and information for agricultural decision makers: A simple conceptual and diagnostic framework. A Guest Editorial. Agric. Meteorol., 142: 91-95.

Stigter, K., 2010. Field Quantification. Chap. IV.9. In: Stigter, K. (Ed.), Applied Agrometeorology. Springer, Heidelberg etc., (In press).

Stigter, C.J. and T. Darnhofer, 1989. Quantification of Microclimate Near the Soil Surface. Appendix F. In: Anderson, J.M. and J.S.I. Ingram (Eds.), Tropical Soil Biology and Fertility: A Handbook of Methods, IUBS/UNESCO, (MAB), C.A.B. International, Wallingford (UK), pp: 144-157.

Stigter, C.J. and N.K.N. Al-Amin, 2007. Zoning and mapping as agrometeorological services in developing countries: Preconditions and requirements in a checklist for action. Paper presented at the COST/FAO/WMO/IBIMET Workshop on Climatic Analysis and Mapping for Agriculture, Bologna, June 2005. Available as hand out and as PowerPoint presentation in use as the opening lecture in Stigter, K., Agrometeorological services: Theory and practice. Roving Seminar, Agromet Vision, Bruchem, the Netherlands and Bondowoso, Indonesia.

Stigter, C.J., C.L. Coulson, A.E. Mohamed, D.N. Mungai and R.M.R. Kainkwa, 1989. Users' needs for quantification in tropical agrometeorology: some case studies. Proceedings of the Fourth Technical Conference on Instruments and Methods of Observation (TECIMO IV), Instruments and Observing Methods Report No. 35, WMO/TD No. 303, Geneva, pp: 365-370.

Stigter, C.J., R.M.R. Kainkwa, A.E. Mohammed and L.O.Z. Onyewotu, 1997. Essentials and Cases of Wind Protection from Scattered Trees and Shelterbelts. In: Bonkoungou, E.G., E.T. Ayuk and I. Zoungrana, (Eds.), Les Parcs Agroforestiers Des Zones Semi-Arides d'Afrique De L'ouest (Parkland Agroforestry of the semi-arid areas of West Africa). SALWA-Network, Ouagadougou and ICRAF, Nairobi, pp: 232.

Stigter, C.J., W. Van den Bor, J.R.V. Daane, H.S. Adam, A.E. Mohammed, J.K. Ng'ang'a and D.N. Mungai, 1998. The ‘picnic’ model for research training at African Universities: evaluation and preliminary comparison. J. Agric. Educ. Ext., 5: 23-38.

Stigter, C.J., R.M.R. Kainkwa, S.B.B. Oteng'i, L.O.Z. Onyewotu, A.E. Mohammed, A.A. Ibrahim and M.G.M. Rashidi, 2000. Measuring wind gradients in agroforestry systems by shaded Piche evaporimeters II. Accuracies obtained in some African case studies. Int. Agrophys., 14: 457-468.

Stigter, C.J., A.E. Mohammed, N.K.N. Al-Amin, L.O.Z. Onyewotu, S.B.B. Oteng'I and R.M.R. Kainkwa, 2002. Agroforestry solutions to some African wind problems. J. Wind Eng. Ind. Aerodyn., 90: 1101-1114.

Stigter, C.J., N.K.N. Al-Amin, S.B.B. Oteng’i, R.M.R. Kainkwa and L.O.Z. Onyewotu, 2003. Scattered Trees and Wind Protection Under African Conditions. In: Ruck, B., C. Kottmeier, C. Mattheck, C. Quine and G. Wilhelm (Eds.), Wind Effects on Trees. University of Karlsruhe, Germany, pp: 73-80.

Stigter, C.J., A.E. Mohammed and N.K.N. Al-Amin, 2004. Use and suitable designs of shelterbelts and scattered trees as well as grasses for protecting agricultural production and infrastructure from wind driven sand encroachment and expanding desertification. Case study of economically beneficial agrometeorological applications and services and of other success stories in agrometeorology for policy matters. W. Baier (Coord.) CAgM Rep. 93, WMO/TD No. 1202, Geneva, Annex 7, pp: 36-39.

Stigter, C.J., S.B.B. Oteng’i, K.O. Oluwasemire, N.K.N. Al-Amin, J.M. Kinama and L.O.Z. Onyewotu, 2005a. Recent answers to farmland degradation illustrated by case studies from African farming systems. Ann. Arid Zone, 44 (3): 255-276.

Stigter, C.J., S. Oteng'i, N.K.N. Al-Amin, L. Onyewotu and R. Kainkwa, 2005b. Wind protection designs from measurements with simple wind equipment in four African countries in research education capacity building projects. Paper 4.1 in WMO Technical Conference on Meteorological and Environmental Instruments and Methods of Observation (TECO-2005). Instruments and Observing Methods - Report No. 82-WMO/TD-No. 1265, pp: 7. (Also available from WMO on CD-ROM).

Stigter, C.J., L.O.Z. Onyewotu and N.K.N. Al-Amin, 2005c. Wind and Agriculture; An Essential Subject of the African Participatory Research Agenda. Paper #103. In: Naprstek, J. and C. Fischer (Eds.), The Fourth European and African Conference on Wind Engineering. ITAMAS, Prague, pp: 11. (Available on CD-ROM and in Book of Extended Abstracts, pp: 306-307.

Stigter, C.J., J. Kinama, Y. Zhang, T. Oluwasemire, K.O. Zheng Dawei, N.K.N. Al-Amin and A.T. Abdalla, 2005d. Agrometeorological services and information for decision-making: some examples from Africa and China. J. Agric. Meteorol. (Japan), 60: 327-330.

Watson, A., 1989. Wind Flow Characteristics and Aeolian Entrainment. In: Thomas, D.S.G. (Eds.), Arid Zone Geomorphology, Belbowen Press, London, pp: 209-231.

Wilson, S.J. and R.U. Cook, 1980. Wind Erosion. In: Kirkby, M.J. and R.P.C. Morgan (Eds.), Soil Erosion. John Wiley and Sons, New York, pp: 217-251.

Wisse, J.A. and K. Stigter, 2007. Wind Engineering in Africa. J. Wind Eng. Ind. Aerodyn., 95: 908-927.

WMO, 1989. Land management in arid and semi-arid areas. Technical Note No. 186, WMO-No. 662, Geneva, pp: 148.