SCATTERED TREES AND WIND PROTECTION UNDER AFRICAN CONDITIONS

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Abstract

Interests in western environments are these days mainly on the effects of wind on trees. However, under African conditions attention is focused on the influence of scattered trees on wind. Such scattered trees in so called agroforestry parklands or other tree densities lower than those of forests, in addition to productive functions have protective functions by reducing and modifying air movement. Strong winds, that may be responsible for carrying soil particles or dry biomass, or/and for mechanically or structurally damaging trees, are reduced. This way, moving particles are settled, soils are protected from wind erosion and damage to (inter)crops is reduced. Air also may carry heat or cold that have less negative impacts downwind when the airflow is altered and reduced by trees. In recent papers of the TTMI-Project, examples from Africa have been treated illustrating these effects with case studies. In this paper we particularly handle (i) air movement around scattered trees and grasses for settling blown sand in Sudan; (ii) air movement reduction by tree crowns assisting hedges to prevent mulch to be blown off from the soil and to protect maize/bean intercrops from mechanical damage in Kenya and (iii) the more general consequences of earlier conclusions from wind reduction observations in savanna woodland of various tree densities in Tanzania. From earlier research on shelterbelts in Nigeria, we also recommend pilot projects on economically useful scattered trees for protection from advected hot dry air. It may be concluded that scattered trees of the right densities have beneficial influences on wind by modifying flows in such a way that mechanical damages and the flow capacities to carry soil particles and biomass are sufficiently reduced. Choosing the right trees and densities for different purposes should, however, be supported by more to the point research.

Introduction

Smallholder agriculture in Africa suffers at many places from strong and/or desiccating winds (Stigter et al., 2002). It was earlier reviewed that these cause mechanical damage to trees, soils and crops, dry out crops, move protecting biomass around or cause sand to invade crop fields and/or endanger infrastructure, limiting or even prohibiting agricultural production. Trees in agroforestry solutions play an important protective role in solving such problems in Africa (Stigter et al., 2002). Indeed the long held view that conservation of water was the main benefit of wind shelter was already rejected in the late seventies and early eighties of the former century, bringing morphogenetic responses, direct mechanical injuries and sandblast damage into the picture as important issues (Stigter, 1985).

In environments of industrialized countries, interests are these days mainly on the effects of damaging winds on trees. However, under African conditions attention is focused on the influence of scattered trees on wind and its consequences. Such scattered trees in so called agroforestry parklands, or in other tree densities lower or differently arranged compared to those of forests, in addition to productive functions have protective functions by reducing and modifying air movement. Strong winds, that may be responsible for carrying soil particles or dry biomass, or/and for mechanically or structurally damaging soils, crops and trees, are reduced. This way, moving particles are settled, soils are protected from wind erosion, damage to inter-crops is reduced. In scattered tree arrangements as well as in design of shelterbelts there is self-protection by front trees facing and modifying the wind speed and its consequences. Air also may carry heat/cold that have less negative impacts downwind when airflow is altered and reduced by trees (Onyewotu and Stigter, 2003).

The Traditional Techniques of Microclimate Improvement Project (1985 – 1998) dealt with a series of wind sub-projects in which trees played mostly protective roles, occasionally with additional productive capacities. These were in particular related to: (i) wind reduction from scattered savanna woodland trees, in Tanzania (Kainkwa and Stigter, 1994); (ii) protection of irrigated land from wind driven moving sand by irrigated shelterbelts (Mohammed et al., 1996a) and by growing protective vegetation in secondary source areas of this sand in Sudan (Stigter et al., 2002); (iii) combating desertification by land reclamation, insufficient crop/yield protection and yield damage by rainfed multiple shelterbelts in Nigeria (Onyewotu et al., 1998; 2003a); (iv) protection of soil and deposited mulches as well as a maize/bean intercrop by hedges in combination with suitable trees in Kenya (Oteng'i et al., 2000) and (v) wind protection of coffee by large umbrella shade trees in Tanzania (Stigter et al., 2002).

In this paper we want to highlight the more general consequences of earlier conclusions drawn from the Tanzanian work with scattered trees, the air movement reduction in the Kenyan demonstration plots and the air movement around scattered trees and grasses for settling blown sand in Sudan. We also want to recommend pilot projects on economically useful scattered trees for protection from advected hot dry air, using the negative experience from the multiple shelterbelts in Nigeria.

Theoretical and quantitative aspects of wind and air movement near trees and shelterbelts and their consequences in our African case studies have been dealt with at several occasions (Spaan and Stigter, 1991; Mohammed et al., 1996b; Stigter et al., 1997; Mohammed et al., 1999; Kainkwa and Stigter, 2000; Stigter et al., 2000; Onyewotu et al., 2003b). They will not occur again explicitly in this paper, where we will concentrate on practical aspects of what we learned from our African sub-projects.

It is also important to consider the influence of expected environmental changes and calamities. We will consider reduced tree densities in detail below. It is important to refer here to Stigter et al. (2003) with respect to aspects of increasing climate variability and climate change. They conclude that in the existing scenarios wind (flow of momentum) is among the parameters that are changing and will continue to change, with peak winds during calamities being the most important aspect of increasing climate variability.

This is of immediate importance to our wind protection related work, but the African farmer will generally not have to take precautions different from those that have been taken in the recent past and at present, be it only very locally and on a much too small scale (Stigter et al., 2003). The problems in Africa are to find, through local innovations, ways to economically and sustainably fight natural disasters, increasing but sometimes decreasing due to natural and anthropogenic factors. Among them desertification, deforestation, wind erosion and some other forms of land degradation have wind related components.

Our work particularly illustrates the unique approach necessary for solving each and every local scale wind problem in Africa, when using trees and other wind reducing vegetation. It are the theoretical and quantitative aspects they have in common that bind them. Therefore it will be necessary to draw conclusions on the extrapolation of these aspects for use in other places and under other conditions, with emphasis on indigenous innovations.

Conclusions from the early Tanzanian work and the more recent Nigerian work

The most important conclusions that can be drawn from the wind reduction studies in the mainly *Acacia tortilis* (Forsk) Hayne Savanna woodland in Tanzania have to do with the importance of biomass distribution with respect to the reduction of wind flow and with the degree of de-coupling of canopy flow and main flow over the woodland. The picture is of course complicated by gusts, and in sparser canopies, or at high biomass density gradients, by preferred differences between flow regimes, of which tunneling is an obvious example (Stigter et al., 1997).

As observed earlier there are few quantitative or theoretical studies on airflow among scattered trees in dryland conditions such as in Africa (Stigter, 1994a). What is clear from indigenous knowledge and oral history is the reduction of wind protection with the thinning of tree densities in agroforestry parklands and woodlands (Stigter, 1994b). This does increase asymmetrical air pressures on plant parts, which lead to well known movement phenomena of tree/plant parts and all kinds of damages observed (Stigter et al., 1997). It also increases heat loads due to advected air, with resulting damages (Onyewotu and Stigter, 2003).

The Tanzanian work quantitatively confirmed the former issue and the Nigerian work with multiple shelterbelts the latter. Stigter et al. (2002) have summarized these quantitative results in the first case and Onyewotu et al. (2003b) in the second case. The conclusions are that in wind protection a medium high biomass density and a rather even spatial biomass distribution, with a somewhat lower density at the bottom, are preferable for scattered trees as well as for shelterbelts. But the former are most suitable for crop protection in African drylands (Stigter et al., 1997). Annex 1 lends support to this conclusion as reached by Onyewotu et al. (2003b) from their shelterbelt work and shows the necessary socio-economic context. However, this same conclusion strongly needs on-farm verification in a participatory approach as these days advocated (Onyewotu and Stigter, 2003).

We can give some hints on the methodological strategies planned to follow in such a verifying sub-project (Onyewotu and Stigter, 2003). It would have the title “A comparison of yields in prevalent cropping systems (i) due to efficiencies of crop protection in intercropping systems with scattered economically useful non-forest trees in appropriate densities and (ii) grown between multiple shelterbelts, where possible improved by adding such scattered trees to existing situations”.

Field trips will be undertaken to potential research areas, to identify target groups and participating farmers. Information on indigenous/traditional knowledge and innovations will be updated through interviews and workshops. Enrichment planting of multipurpose tree species preferred by farmers (e.g. trees of food or medicinal value but which mainly utilize a horizon deeper than crops to obtain water and nutrients) will be carried out jointly by farmers and researchers in the present agroforestry farms and between the shelterbelts. Yields of (inter)crops and wind protection efficiencies in parkland agroforestry of different tree composition and density will be compared. Other microclimate conditions within the plots, including water use, will be determined to understand differences with tree density and with growing stage of trees. Use of the maximum affordable organic manure for sustainable and environmentally sound agricultural production will be encouraged, since the present level is inadequate. While encouraging an increase in the use of organic manure, supplementary application of inorganic fertilizer, in an improving socio-economic setting and availability, would result in higher productivity and better environmental management. The sub-project will give special attention to creating a policy environment for pro-poor agricultural extension and extension agrometeorology. For this purpose it will envisage to collaborate in the training of suitable extension intermediaries between those creating the scientific results/products of the project and the target groups of farmers in need of agrometeorological services (Stigter, 2002 a; 2002 b; 2002 c; Stigter et al., 2003).

Trees and grasses settling blown sand

As was long ago reviewed by Stigter et al. (1989), design of windbreaks particularly aims at guiding airflow over, into and through shelterbelts and other arrays of various tree densities and arrangements. Factors considered are belt or windbreak shape, composition, height, length and width, direction, distance between belts, number of multiple belts and permeability of belts. Mohammed et al. (1996a) considered these factors with respect to the design of shelterbelts for sand protection. Their concerns were derived from a case study in which irrigation canals and irrigated land had to be protected from windblown sand during that part of the year that the wind was blowing towards parts of the Gezira scheme, Sudan.

Under the conditions of maximum sand deposition within the shelterbelts, in the first 10 meter near the edge, of about 20 cm per year, the front trees survived the sand deposition. Apparently root development was such that the irrigation water kept reaching the roots of these front trees. Sand was found till about 30 m within the belt, that was made up of *Eucalyptus microtheca* trees of less than 7 m, spaced at 3 m distances. It was estimated that 20 to 30 m would have been sufficient for the width of the belt in these early years but wider belts gave more storage space for accumulating sand.

Separate consideration was given to advice on trees to be used in such designs. Growth rate, life span and tolerance for drought, heat, pests and diseases, grazing, sand blast and sand deposition were mentioned. Canopy geometry and byproducts were considered with respect to air flow and economy. It was proposed that dense shrubs in the front row(s) followed by tall strong trees would do best from the windward wind reduction point of view. The use of such shelterbelts nevertheless demands for concern about lasting sand deposition that can only be prevented if sand can be deposited/stored in the primary or secondary source areas of the sand.

	Height (m)	Permeability	Wind dir.	Sand caught (on a scale of 1 (low) to 10) Leewards	Windward	Inside tree
Lp 1	2.5	Low	N/E	10	9	10
			S/W	2	6	10
Lp 2	4	Low	N/E	9	3	9
			S/W	1	8	9
Lp 3	1.6	High	N/E	3	2	--
			S/W	1	4	--
Lp 4	2	High	N/E	2	1	--
			S/W	1	1	--
Pj 1	2.5	Medium	N/E	9	3	9
			S/W	2	1	9
Pj 2	3	Medium	N/E	10	3	--
			S/W	10	4	--
Pj 3	Cluster		N/E	10	10	10
			S/W	10	10	10
Pt 1	0.8	Low	N/E	9	1	--
			S/W	9	1	--
Pt 2	1	Medium	N/E	6	2	--
			S/W	1	1	--
Pt 3	0.9	Medium	N/E	6	2	--
			S/W	3	1	--
Pt 4	Cluster		N/E	9	1	--
			S/W	9	1	--

Table 1 Examples of sand trapping capability of *Leptadenia pyrotechnica* (Lp) and *Prosopis juliflora* (Pj) trees, as well as *Panicum turgidum* (Pt) grass, of different permeabilities

For this purpose Al-amin et al. (in preparation), after having established that the primary and a secondary source area of the blown sand laid beyond the White Nile, investigated the capability of indigenous natural vegetation to be established under the harsh conditions of the area. They found that establishment under lower irrigation frequency and a certain tolerance for salt and sodicity were requirements for survival and suitability for revegetation of the secondary source area in front of the Gezira scheme (Stigter et al., 2002).

Table 1 illustrates the sand settlement results obtained as summarized for the most suitable species reported in Stigter et al. (2002) and Al-amin et al. (in preparation). Low and to a certain extent medium permeability as well as the formation of clusters enhance sand trapping at all sides of the trees and grasses, rather independent of wind direction. N/E wind direction did sometimes slightly better and there were notable differences between leeward and windward sides, both as a function of biomass density distributions. It may be concluded that scattered trees and grasses of the right kinds, densities and permeabilities have beneficial influence on wind by modifying flows in such a way that the flow capacities to carry saltating and creeping soil particles are sufficiently reduced. However, such re-vegetation has to occur over large areas.

Hedges with trees protecting soil, mulches and intercrops

The wind related results in Kenya have already been widely published (Oteng'i et al., 2000; Stigter et al., 2002) and details of on-station as well as on-farm research results can be found in these and still forthcoming publications. It is another example of a typically local problem, experienced in this case by farmers that were forced to emigrate from higher potential areas in Kenya, because of population pressure and carrying capacity problems of the land available in their areas of origin. Demonstration farms had to be set up to introduce mulched agroforestry, to make it possible for them to keep growing their maize/bean intercrops to which they were used. During part of the growing season strong winds are experienced. The following results were obtained:

- it appeared necessary to use *Colleus barbatus* hedges all around the plots to prevent the necessary maize stalk mulches from being blown off the plots;

- these hedges had to be root pruned to prevent or at least diminish competition between the trees in the hedges and the crops;

- combining this system with *Grevillea robusta* trees made it economically more attractive and made it aerodynamically more efficient to diminish mechanical damage to the intercrops and improve soil water availability to these crops, as long as the trees were also root pruned;

- gaps in the hedges could be devastating if in the direction of prevailing winds;

- gaps between the top of the hedges and the lowest biomass of the trees diminished the protection efficiency of the agroforestry system;

- turbulence generated by buildings and large trees near to the demonstration plots negatively influenced crop growth locally, indicating the sensitivity of the crops for mechanical wind damage by the winds concerned.

It may again be concluded that some configurations of trees, with the right distributions of biomass, can modify airflow positively and in this case sufficiently reduce mechanical damages of the protected crops and prevent the blowing off of mulches. However, strong biomass gradients, such as in gaps, as well as generation of additional turbulence should always be prevented, like this was also the case in the design of shelterbelts.

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Annex 1 (from Onyewotu et al., 2003b)

It may be concluded that the sharp drop in yield in the wake zone must be attributed to the combined negative effects of high turbulence (worsened by the shelterbelts) and advected heat in this area, together with somewhat higher wind speeds. In the seedling stage these were effects on the physiological development of the crop, and in all stages on stomatal resistance, reducing respectively evaporation and water uptake as well as carbon dioxide intake. High turbulence and advected heat increased evaporative demand, demonstrated in this study by initially lower soil moisture in the surface layers (Onyewotu et al., 1998) and the occurrence of high Piche evaporation values. On the basis of our findings and earlier results reported on already elsewhere, the following recommendations/weather advisories may be made:

(i) Between shelterbelts like those at Yambawa, the wake zone, where most of the (increased) turbulence occurs, should be suppressed. This can be done by reducing the space between the belts as they are presently positioned to as small as 7h or with our trees 85 m, the extent of effective shelter in our case, in the Yambawa area. With a crop height of 1.5 m, fullest protection may only occur with 75 m distance.

(ii) New multiple shelterbelts should be established along an axis such that they will be most effective in reducing wind speed, i.e. perpendicular to the direction of prevailing winds. In this way the size of the quiet zone or the area of effective shelter will be increased, in our case with as much as 30% (Onyewotu, 2003a). In this case additional measures would have to be taken to reduce sand movement in the dry season.

(iii) The present height of the Eucalyptus belt is sufficient as a wind barrier, but higher trees of equivalent suitability would be an improvement. They can be afforded because of the relatively low wind speeds in the area. Windward architecture that aerodynamically reduces the generation of turbulent eddies would very likely increase the distances allowed between belts (Stigter et al., 1989).

(iv) If the high demand for arable land in the region is taken into account and if it is recognised that the implementation of recommendation (i) above implies that more land could be taken up by shelterbelt establishment, it should be acknowledged that this is a situation which would be most unwelcome to rural land owners, especially if a commensurate compensation is not paid.

(v) Scattered trees (parkland agroforestry) of sufficient density and properly pruned may be more suitable for intercropping under conditions of heat damage or mechanical damage by wind than shelterbelts, due to the small distances required between shelterbelts (see also Kainkwa and Stigter, 1994; Oteng'i et al., 2000). Such trees should be selected by farmers.

To strike a balance between more efficient shelterbelt establishment and conservation of arable land, the following is recommended for the already planted Yambawa belts:

(a) The width of the present belts should be kept within the limits of an acceptable minimum of something like 15 m (i.e. 5 rows of trees at a spacing of 3 m x 3 m) per belt instead of the present 30 m (10 rows of 3 m x 3 m).

(b) One way of drastically reducing the width of the present belts is by taking away 5 rows so that the space between the belts could become wider. It would then be possible to re-establish at least one new line of 5 rows wide in between. Between the presently widest spaced belts two new belts have to be established. This will bring the spacing between the belts very close to or within the interval recommended in (ii) above.

(c) Farmers displaced by this exercise should be adequately compensated.

(d) Alternatively, farmers should be allowed and assisted to plant a low density of scattered trees of their choice between the present shelterbelts or between the present kind of belts made less wide, because such scattered trees occur naturally in the area.