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EFFECTS OF SHELTERBELTS IN THE SUDAN SAVANNA ZONE OF NIGERIA ON MICROCLIMATE AND YIELD OF MILLET

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ABSTRACT

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Results of field experiments to measure the influence of shelterbelts on wind velocity, air temperature, soil temperature, soil moisture and yield of millet in a semi arid environment are presented. It was found that the shelterbelt reduced wind velocity (measured at 2 m above the ground surface) on the leeward side. The reduction in wind velocity ranged from 20 to 10% at distances of 20 and 150 m, respectively, from the belt. Maximum air temperatures were 0.8 to 1.5°C higher at 20 m from the belt on the leeward side than in the open field. Minimum temperatures were, however, of the same magnitudes in both the open and sheltered areas. It is estimated that the moderating influence of the belt on wind extends to a distance of 15 times the height of the trees, while the effect of the belt on air temperature does not extend beyond 10 times the height of the trees.

The influence of the shelterbelt on soil temperature was minimal. Maximum soil temperatures at 5 cm depth were 0.5 to 1.0°C higher close to the belt than in the open. Also, the shelterbelt had little influence on the soil moisture during the rainy season. However, immediately following the end of the rains, moisture depletion from the top soil was more rapid on the unprotected side than on the leeward side as the higher wind speeds on the unprotected side hastened the process of evaporation. Millet yield was higher in the sheltered area than in the open with peak yield observed at a distance of 4 times the tree height.

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INTRODUCTION

In many arid and semi-arid regions of the world, the establishment of forests in areas where natural forests do not grow (afforestation) has been used as a means of alleviating harsh weather conditions (excessive wind velocity, high evaporation and low atmospheric humidity) that often make agricultural practices almost impossible in such areas. In particular, shelterbelts (which are long rows of tree plantings across the direction of the prevailing winds) have been used for many years in developed countries to protect humans, livestock and crops against the ravages of the wind.

A large proportion of Nigeria's land mass falls within the arid and semi-arid zones where severe losses from droughts are experienced almost on an annual basis since the last decade and there has been speculation on the

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gradual encroachment of the Sahara desert (Dalby and Harrison-Church, 1973). Frequent droughts are now considered a major factor in the declining food production in the Savanna regions of Nigeria and the northern neighbouring countries (Kowal and Adeoye, 1973; Mortimore, 1974). The primary function of any surface barrier like the shelterbelt is to reduce wind velocity. However, the consequences of wind speed reduction could also be manifested in the amelioration of other factors which constitute sources of stress to crops; for example, reduction in evapotranspiration, increase in air humidity and prevention of soil temperature extremes are some of the beneficial effects that can result from the presence of a shelterbelt.

Recognising the socio-economic importance of arid zone afforestation, the Federal Government of Nigeria in its first National Development Plan (1962—1968) accorded top priority to the project concerned with amelioration of the climatic and water regimes of the treeless arid areas of the country, especially of the four northermost states comprising Sokoto, Kano, Borno and Gongola. Although shelterbelt developments in Nigeria started over two decades ago, there is a paucity of scientific reports and data regarding their influence on the environment of the protected areas. This paper is therefore an evaluation of the effect of the shelterbelts on wind velocity, air and soil temperatures, soil moisture and yield of millet.

METHOD

The experiment was sited at two locations, about three and a half kilometres apart, at Dambatta (Lat. 12° 27′ N, Long. 8° 31′ E). The shelterbelt lines, each of about 30 m in width, run in an East—West direction at an angle of about 45° to the prevailing NE and SW winds. The tree species is *Eucalyptus camaldulensis* established in 1964 and have attained an average height of 10 m. The belts are of medium density and the distance between adjacent belts is 300 m.

Wind speed measurements were made using cup anemometers located 2 m above the ground surface. Some of the instruments were installed in the unprotected field (windward side) at a distance of 200 m from the belt while others were placed at distances of 20, 40, 100, 150 and 200 m from the belt on the leeward (protected side). Observations were made three days a week at 11.00 a.m. and 2.00 p.m. Screens containing maximum and minimum thermometers were also located on both the windward and leeward sides at the same height and distances from the belt as the anemometers. Readings of these thermometers were taken three times weekly at 8.00 a.m., 12.00 noon and 2.00 p.m. on each day. From these readings, the monthly mean wind velocity, maximum and minimum air temperatures were calculated for the two-year period (1980 and 1981) that the experiment lasted.

To measure the soil temperature, bent-stem soil thermometers were installed at depths of 5, 10 and 30 cm both in the open field and in the sheltered area at distances of 20, 40, 100 and 200 m from the belt. Readings

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were taken at 8.00 a.m., 12.00 noon and 3.00 p.m. three times a week throughout the growing season and after harvest. Soil moisture in the profile was determined gravimetrically in depth increments of 10 cm down to 100 cm depth once a week throughout the duration of the experiment. Millet was planted on 90 cm ridges constructed perpendicularly to the shelterbelt line. Prior to ridging fertilizer was applied by broadcast at the rates of 60 kg N and 15 kg P per hectare. Sowing was done during the first week of July when sufficient rain had been received to ensure good germination and seedling establishment.

RESULTS AND DISCUSSION

The results for the two locations were very similar, hence data for the two sites have been pooled and averages calculated.

Wind speed

Table I shows the influence of the shelterbelts on wind velocity. Observations indicated that wind speeds were mostly in the range of 7 to 16 km h^{-1}. The data in Table I are expressed as percent wind speed reduction on the leeward side with respect to the windward side. The distances given are in multiples of the mean tree height, which was 10 m. It can be seen that the degree of wind speed reduction was greatest closest to the belt with the effect of the trees on windspeed diminishing gradually with increased distance from the belt. The influence of the tree belt on windspeed was, however, still measured at a distance of 20 times the height of trees. The percent wind speed reduction as a function of distance from the belt appears to be approximately the same irrespective of the magnitude of the open-field wind velocity. The distance of effective wind sheltering found in this work is well within the normally accepted range of 10 to 30 times the height of trees (Staple and Lehane, 1955). Furthermore, the belt-spacing of 300 m seems to be adequate, as the tendency of winds to re-establish their open-field velocities is counteracted by the presence of the next rows of trees. In this way, the shelterbelt acts as a barrier in dissipating some of the wind's force and this has the prospect of reducing the amount of soil drift within the sheltered area.

Air temperature

The mean monthly maximum air temperatures in the open and protected areas of the shelterbelt are given in Table II. The values range from 30.0°C in January to 40.9°C in April. It is seen from the table that the highest temperatures were consistently recorded on the leeward side at points closest to the tree belt. However, the temperature differences involved were generally small (less than 2.0°C). The higher temperatures observed close to the belt on the

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TABLE I

Percent mean wind speed reduction in sheltered farmland at Dambatta, 1980/81

Period	Distance from shelterbelt (in multiples of tree height, *H*)				
	2*H*	4*H*	10*H*	15*H*	20*H*
Aug.	19.30	18.7	14.4	12.5	7.0
Sept.	20.1	19.6	15.6	12.6	7.5
Oct.	23.7	20.4	14.6	12.4	8.5
Nov.	19.5	18.4	13.8	8.4	—
Dec.	—	—	—	—	—
Jan.	22.1	20.7	15.4	12.3	6.9
Feb.	19.2	18.7	14.9	9.3	6.5
March	21.5	21.9	14.3	9.9	7.1
April	21.5	21.2	11.1	9.4	6.2
May	21.3	20.9	11.2	9.4	7.7
June	20.9	19.6	16.9	11.6	7.0

TABLE II

Mean monthly maximum air temperature (°C) in open and sheltered farmlands at Dambatta

Period	Open farmland	Protected farmland				
		Distance from shelterbelt (multiples of tree height, *H*)				
		2*H*	4*H*	10*H*	15*H*	20*H*
July	32.1	33.5	33.3	32.9	32.2	32.1
Aug.	32.1	33.9	33.4	32.8	32.0	32.1
Sept.	33.2	34.1	33.8	33.0	33.2	33.1
Oct.	34.3	35.0	34.7	34.4	34.4	34.2
Nov.	34.3	35.2	34.9	34.5	34.6	34.3
Dec.	32.7	33.5	33.3	33.3	33.0	33.0
Jan.	30.0	30.9	30.7	30.0	29.6	30.1
Feb.	31.0	31.8	31.6	31.1	31.0	31.2
March	37.1	38.0	37.5	37.5	37.2	37.2
April	39.8	40.9	40.2	39.7	39.7	39.5
May	38.2	39.0	38.9	38.4	38.1	38.2
June	34.3	35.1	34.8	34.3	34.3	34.1

protected side is probably a reflection of the relatively calm zone existing there. Reduction in wind velocity in the sheltered area probably caused a reduction in heat exchange between the air layers, thus resulting in the higher temperatures. The maximum temperature decreased steadily with

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distance from the belt up to about 15*H* (150 m; *H* = tree height). For example, the mean maximum temperatures in August 1981 were 33.9, 32.8 and 32.0°C at distances of 2*H*, 10*H* and 15*H* respectively. The data for minimum temperature (Table III) do not show any clear trend in temperature variation. Moreover, the differences in temperature within and outside the sheltered area were much less than those recorded for maximum temperatures. Combining the maximum and minimum temperature data, it can be concluded that the mean air temperature which was primarily determined by the maximum, was higher in fields between the belts than in the open.

Soil temperature

The shelterbelt affected the maximum soil temperature at 5 cm depth, had a slight effect on temperature at 10 cm and had no measurable influence on temperature at 30 cm. Temperature observation during the day indicated that the maximum soil temperature at 5 cm occurred at about 3.00 p.m. and Table IV is a summary of the temperature data at this depth for 1980/81. Generally, the maximum temperatures of 38.3° to 39.7°C observed in the top soil during the growing season were well above the upper limit of the optimum range of 25 to 35°C for the growth of hot season crops like maize, sorghum and millet. In fact the temperature recorded showed that the soil temperature at 5 cm depth had exceeded 35°C by noon on most days. Maximum temperatures of the top soil in the zone between 2*H* and 4*H* from the belt in the protected area were 0.5 to 1.0°C higher than in the open. This zone of higher soil temperature corresponds to the zone of maximum wind reduction. The higher soil temperatures at 5 cm depth may therefore be explained on the basis of wind speed and air temperature. Beyond a distance of about 4*H* from the belt, soil temperatures on the lee side were not different from temperatures in the open field.

Soil moisture storage

Observations showed that during the rainy season (July to September) there were no large differences in the soil moisture regime of sheltered and unsheltered fields. This was probably because the soil profile was continually being recharged. However, moisture storage in the profile (0—100 cm) measured at a distance of 2*H* from the belt on the leeward side was about 5% smaller than at other sampling points (Table V). This finding implies that water extraction by the tree roots probably extended laterally up to a distance of 20 m.

The shelter effect on soil moisture became very apparent during the few weeks following the cessation of rains. At the end of September, 1980, the moisture storage in the 0—10 cm soil layer averaged 9, 8, 9, 5, 10.6, 9.8 and 11.2 mm in the open field and on the leeside at distances of 20, 40, 100 and 150 m from the belt respectively. By the end of October, however, the corresponding storage figures were 2, 4, 2, 9, 4, 1, 3.5 and 3.1 mm,

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TABLE III

Mean monthly minimum air temperatures (°C) in open and sheltered farmlands Dambatta

Month	Open farmland	Protected farmland				
		Distance from shelterbelt (multiples of tree height, *H*)				
		2*H*	4*H*	10*H*	15*H*	20*H*
July	22.5	22.4	22.2	22.0	22.5	22.4
August	22.5	22.5	22.4	22.3	22.3	22.2
Sept.	23.1	23.3	23.2	23.4	23.4	23.2
Oct.	23.1	22.9	23.0	23.1	23.2	23.2
Nov.	18.0	18.1	18.2	18.0	18.0	17.9
Dec.	14.3	14.5	14.3	14.0	14.2	14.2
Jan.	14.9	15.2	15.0	15.1	15.1	15.0
Feb.	20.1	19.8	19.8	20.0	20.1	20.2
March	21.3	21.5	21.3	21.6	21.4	21.4
April	24.8	25.1	25.0	25.3	25.1	24.9
May	26.4	26.2	26.0	26.1	26.5	26.4
June	23.6	23.7	23.4	23.5	23.6	23.6

TABLE IV

Mean maximum soil temperature (°C) at 5 cm depth in sheltered and open farmlands a Dambatta (1980/81)

Period		Open farmland	Protected farmland			
			Distance from belt (multiples of tree height, *H*)			
			2*H*	4*H*	10*H*	20*H*
July	1980	38.4	38.7	38.5	38.6	38.5
Aug.	1980	38.3	39.1	38.8	38.9	38.4
Sept.	1980	39.1	39.71	39.5	39.2	39.4
Oct.	1980	40.4	39.9	40.0	40.0	40.2
Nov.	1980	39.8	39.6	39.7	39.8	39.7
Dec.	1980	—	—	—	—	—
Jan.	1981	37.4	37.7	37.5	37.6	37.4
Feb.	1981	39.5	39.7	39.4	39.6	39.6
March	1981	42.1	42.0	42.0	41.9	41.9
April	1981	43.2	43.4	43.1	42.8	43.0
May	1981	42.2	42.5	42.3	42.3	42.1
June	1981	39.8	39.7	39.7	39.6	39.7

TABLE V

Water storage (mm) for 0—100 cm soil depth in sheltered and open farmlands, 1980

Date	Open farmland	Protected farmland			
		Distance from belt (multiples of tree height, *H*)			
		2*H*	4*H*	10*H*	15*H*
7 July	170.9	164.1	174.7	170.7	177.6
28 Aug.	120.9	115.6	120.1	117.6	119.7
29 Sept.	100.4	95.0	101.9	99.2	102.5
30 Oct.	39.2	48.5	47.5	44.8	49.8

representing, respectively, 76, 69, 61, 64 and 72% reduction in moisture over a period of four weeks. These differences in moisture storage of the surface layer can be ascribed to evaporation. During the period, environmental factors were probably the most important in controlling the rate of evaporation from the soil. Since the drying power of the atmosphere is related to wind speed, the zone of least evaporation corresponded with the zone of maximum reduction in wind speed, as expected.

Total soil moisture depletion calculated as the difference between moisture storage at planting and at harvest plus rainfall over the growth period showed no significant differences due to position from the belt. However, moisture use averaged 18.6, 2.3 and 4.6 mm higher at distances of 2*H*, 4*H* and 5*H* on the leeward side than in the open farmland. Again the higher moisture depletion close to the belt could be attributed to the activity of the tree roots.

Crop yield

In Table VI, the yield of millet in the protected side is given as percent of yield in the unprotected area. It can be seen that crop yield varied with distance from the belt and the yield at 4*H* was higher than the yield for any other area in the protected side and significantly higher (at 5% level of probability) than yield in the open field. The percent increases in yield as a result of the shelterbelt are, however, lower than those reported for either wheat, barley or oats in the U.S.A., U.S.S.R. and in Western Europe (George, 1960). One feature of the data in Table IV is that the yield trend is generally similar to the pattern of wind speed reduction; the lower yield at 2*H* compared to 4*H* could be a result of competition between roots of trees at the edge of the belt and the crop for moisture and nutrients. Shading was probably not an important factor in reducing yield at 2*H* since the orientation of the belt is the same as the direction of the sun's movement (East—West). During the two years of the experiment, soil moisture did not appear

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TABLE VI

Grain yield (% of open farmland) at various distances from the belt

Distance from belt (multiples of tree height, *H*)				
2*H*	4*H*	10*H*	15*H*	20*H*
115	121	115	110	107

to be a limiting factor in the growth of the millet crop. The reason for the yield pattern obtained is therefore not very clear, but it could be that the reduction in wind speed in the sheltered area reduced the evaporative or wind stress on the crop.

In both years of the investigation, the open field wind speeds recorded were generally higher between December and April than at any other time. During this period, the area under study is under the influence of the North East Trade Winds (the Harmattan). The Harmattan is always heavily laden with fine soil material which causes discomfort to both humans and animals. The amount of wind-blown material has been estimated by Bromfield (1974) to be in the range of 50 to 250 kg/ha/annum. Although the quantity of wind blown material was not measured in this investigation, it is known to be a function of the wind velocity (Chepil, 1945). The reduction of wind velocity between the shelterbelts would be expected to reduce soil blowing by 10 to 20% thus reducing soil erosion and deposition of dust on dry season crops. With a dry season lasting 5 to 7 months, irrigation appears to be the major method of increasing food production in the northern Guinea, Sudan and Sahel savanna zones of Nigeria. There are, however, climatic limitations to dry season agriculture in these regions: air temperature extremes, desiccating and dust laden winds. The last two conditions could probably be ameliorated by establishing shelterbelts, windbreaks and farmtrees.

Although the scope of this work was limited to investigating the effects of shelterbelt on the microclimate especially as it affected crop growth, it is known that shelterbelts also protect humans and their livestock against the ravages of the weather. These last aspects are difficult to quantify but it may be in this area of human and animal comfort that the prospects of shelterbelt establishments are good. A large proportion of the farming population in the northern Guinea and Sudan zones still live in scattered homesteads and provision of wind barriers of living trees and shrubs for protecting the farmstead (farm home, garden and livestock lots) could increase productivity of the livestock and improve the socio-economic life of the people by making the environment more hospitable.

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