EFFECT OF SHELTERBELTS ON SOIL MOISTURE AND TEMPERATURE REGIMES OF SOILS AT DAMBATTA (KANO STATE) NIGERIA

BY

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CERTIFICATION

This Thesis entitled 'Effect of Shelterbelts on Soil Moisture and Temperature Regimes of Soils at Dambatta (Kano State) Nigeria', by Job Edwin Ujah, meets the regulations governing the Degree of Master of Science, Ahmadu Bello University, Zaria and is approved for its literary presentation and contribution to Scientific knowledge.

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A B S T R A C T

Any accelerated increase in world food production depends on the improvement of agriculture in the tropical and sub-tropical regions of the world. To achieve these objectives, there must be an adequate relationship between forest belts and arable lands.

The influence of forests on the amelioration of adverse weather conditions in adjacent farmlands was examined at Dambatta in Kano State of Nigeria by measuring the surface wind speed, air and soil temperatures, soil moisture storage and crop yield in sheltered and unsheltered farmlands.

The results showed that shelterbelts improved the weather condition of farmlands in the area through the reduction of surface wind speed immediately behind the shelterbelt by an average of 20.8%. With increased distances from belt, percentage wind reduction decreased to about 5.2% at a distance of 300m. away from the belt, The observed air temperature of 34.7C and 35.6'C in the protected areas 20m away from the belt in sites 1 and II respectively were higher than the corresponding figures of 34.4.C and 34.C in the open farmland. The mean soil temperatures at the depth of 5cm were 35.7.C and 36.6.C on sites 1 and II respectively

immediately behind the belts and 35.C and 35.8.C in the open sides.

The total soil moisture storage to a depth of 100cm on the protected land was higher than in the unprotected area. It averaged 533.6mm for site 1 and 554.7 for site II were 502mm and 491. 2mm respectively.

The mean yield of millet on site 1 at 40m from the belt was significantly higher (1% level) than the mean yield at other distances. For site II, yield was significantly higher (5% level) than the mean yield at other distances from the belt.

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1. INTRODUCTION

Afforestation to create shelterbelt is very necessary in arid and semi-arid regions of the world where excessive wind velocity, scanty annual rainfall, high radiation intensity, high evaporation rate from the soil surface, low atmospheric humidity and other adverse weather conditions make agricultural practices almost impossible.

By definition, afforestation is the establishment of forests in areas where naturally forests do not grow. Similarly, shelterbelts are long rows of tree plantings across the direction of prevailing winds with a view to protecting the adjacent farmlands and livestocks against the damaging force and other associated dangers of the winds. Aridity is denoted by the very low amount of annual rainfall characteristic of a given ecological zone. When the maximum annual rainfall of any region never exceeded 500mm, such a zone is classified under a semi-arid zone. For arid zone, it is a maximum of between 200 - 300mm. The recognized ability of shelterbelts to improve harsh weather conditions of a given ecological zone had stimulated the interest of advanced nations, like the U.S.A., Canada, U.S.S.R., Denmark, China, Japan, Israel etc., to embark on shelterbelt afforestation programmes in their respective problem areas.

Greater proportion of Nigeria's land-mass falls within the arid and semi-arid zones where seasonal and annual droughts are aggravated by high wind velocity resulting in excessive loss of already scanty soil moisture.

These adverse environmental factors hamper every effort to produce sufficient food crops to cope with the ever-increasing population in this part of the country in particular and Nigeria in general. The excessive loss of soil moisture which is a major constraint in crop production, needs to be guarded against in these areas in order to achieve the Federal Government's objectives in the Green Revolution Programme.

In order to do this, the micro-climate and soil climate of the area have to be modified through afforestation and research. The establishment of forests takes time to evolve and when fully developed, the trees consume a lot of soil water thereby adding to the shortages of soil moisture near the edges of the belt. Although this is counted as a disadvantage, it is outweighed by other numerous advantages of the shelterbelt. This is examplified in Adeyoju (1973) that the present shelterbelt establishment appears to be accepted as beneficial by some villagers in Kano State.

Dambatta in Kano State, situated at about latitute 12½ °N, is one of such areas with arid-zone characteristics. Very little or no work has been done in Dambatta or elsewhere in Nigeria's arid environment regarding the effects of shelterbelt on soil climate.

It is therefore the aim of this work to study the effect of afforestation on wind speed, air and soil temperature and moisture regimes of soils at Dambatta.

2. LITERATURE REVIEW

Effect of shelterbelt on wind speed, air and soil temperatures, soil moisture and other elements of weather is mostly studied on fields between shelterbelts and, for the purposes of comparison, in the open fields. Several workers in different climatic zones of the world have shown what can be achieved by establishing shelterbelts and wind-breaks in those regions of the world where the climatic conditions are very unfavourable for agricultural production, livestock improvement and human comfort. In many of their reports, emphasis was placed on the orientation of the belt to the prevailing winds, width, density and height of the shelterbelt as important factors determining the effectiveness of the belts in relation to air flow.

2.1 THE INFLUENCE OF SHELTERBELT ON WIND SPEED

Panfilov (1937) on his studies on the effect of shelterbelt on wind speed, used anemometers installed at various distances from the shelterbelt on the leeward and windward sides. Results obtained from a periodic anemometric observation generally showed a greater reduction in wind speed in the lee side of the belt in comparison with wind speed in the open field. Within the belt's lee side, maximum reduction was reported nearest the belt followed by gradual rise in speed with departure from the belt. Tracing the trend of the changes in wind velocity from one distance to another he found that the extent of shelter effect terminates at 30H beyond which wind speed evens out with those in the open field. (H = distance from the belt in multiples of tree height).

In the same studies, Panfilov assessed the degree of wind reduction at various intervals from the belt, and estimated the sharpest reduction in wind velocity within a zone of between 10H and 15H on the lee side, and approximately 5H on the windward side. According to him, the greatest wind reduction occurred behind belts perpendicular to the prevailing winds, but this reduction decreases sharply as the angle between the direction of shelterbelt and a line perpendicular to the prevailing winds decreases. He also found that any shelterbelt in an orientation of less than 30° to the prevailing winds has no protective effect.

Naegeli (1946) in similar studies, not only drew similar conclusion to Panfilov's but made a break through in wind speed studies by establishing the percentage limit over which shelterbelt has no influence on wind speed. He observed a 30 percent reduction in wind speed at 1H and 10% at 18H. On the basis of his results and practical experience, he established that shelterbelt ceases to be effective from the point where the percentage wind reduction falls below 10 percent.

Many research workers agree in principle that shelterbelt protect the adjacent areas against inherent adverse weather factors, but the extent of protection varies according to climatic zones and other associated factors from 1 to 10H windwards and 7 to 60H leewards. The conclusions of Matjakin (1952), Woodruff Read and Chepil (1959) and George (1960) seem to agree in principle with the early observations of Naegeli and Panfilov, who drew attention to the fact that shelterbelt is effective up to

approximately 30 - 40H, and that the extent of sheltered zone ends where wind reduction is less than 20 percent or at least 10%.

Caborn (1957) in his studies on the effect of various widths and densities of belt on wind reduction, found narrow belts more effective in reducing wind speed than wider ones. Behind dense belts of 10 rows, he recorded a maximum of 40 percent wind reduction occuring at about 2.4H while with medium dense belt 25% reduction was recorded at equivalent distance from the belt. Very dense and very loose belts offered no appreciable protection because of eddies and turbulent mixing of air found behind very dense belt and because of the high porous nature in the case of very loose belt which makes the belt not effective. After examining various widths of belts, Caborn found 11 - 19H apart very effective hence he concluded that the effectiveness of a shelterbelt depends on its width and density.

According to Molski (1966) wind reduction is greatest behind a very dense shelterbelt, but over a very short distance which indicates that a very dense belt offers only a narrow zone of effective shelter. He observed that a shelterbelt of medium density reduced wind speed more slowly and to greater distance from the belt. He therefore concluded that the sheltered zone is broadest with a medium dense shelterbelt.

Published results of research into the effect of wind speed and its direction on the development of agriculture, Dawry et al (1976) indicated that wind speed as well as the dryness of the air masses are more important than wind direction per se. They noted that the diurnal variation of surface wind in the open farmland

during the dry season often resulted in higher speeds near mid-day when high insolation, temperature and wind all combined to increase the evaporative demand of the atmosphere and the stress on plants. Within the lee side of a medium dense belt despite the observed higher temperature they reported a decrease in the evaporative demand of the atmosphere and less stress on plant due to reduced wind speed.

2.2 INFLUENCE OF SHELTERBELT ON AIR TEMPERATURE

According to Anon (1962), a shelterbelt alters temperature and radiation conditions, an assertion which he made after studying the effect of shelterbelt on air temperature in the windward and leeward sides. He however pointed out that shelterbelt causes higher temperature during the day and lower temperature at night. He further noted that the influence of forest belts on air temperature is due to reduced wind velocity, which perceptibly affects the temperature of a calm zone near the lee edge thus reducing the exchange between lower and upper air layers. But any trend in temperature different from what is said above is due to the protection of the soil by tree canopy against direct insolation and radiation. He then stressed that the insulation of tree canopy retards daylight warming and night cooling of the air layer nearest the ground within the forest belt.

The study by Bodroff (1936) on the effect of shelterbelts on air temperature at different distances from the belt indicated the occurence of higher temperature in the protected area than in the open field during the first half of the day when heat balance is

positive, but in the second half of the day, when heat balance is negative, he observed a lower temperature in the protected area than in the open field: a phenomenon which, he explained, is a result of reduction of vertical diffusion and mixing of air. This differences in temperature, he noted, may be favourable to some crops but harmful to others. Further results from simultaneous measurements of air temperature and wind speed behind dense and medium dense belts, showed a zone of complete calmness with a corresponding higher air temperature behind a dense belt than in the open field. Similar situation also occurs behind a medium dense belt but with lower values than behind dense belt. He therefore concluded that the influence of shelterbelt on air temperature depends mainly on reduced wind speed which only affects the temperature of the completely calm zone near the lee edge thus reducing the exchange between lower and upper air layers.

Burnacki and Golcberg (1951, 1952) working with dense and medium dense belts found increase in temperature within a distance of 5 to 7H of a dense belt, while with medium dense belt the area of temperature increase extended to 6 - 8H leeward. This indicates that dense belts influence air temperature within a narrower zone behind the belt than medium dense belts. The maximum difference they observed between the temperatures in the protected and open fields hardly exceeded 3°C for both structures but was rarely zero. The increase in temperature at the edge of a dense belt by day and decrease at night rarely exceeded 2°C, while the minimum temperature at night was about 2.5°C below the temperature in the open field.

When the soil was wet, greater differences in temperature were observed than when the soil is dry. This is due to the fact that evaporation from the soil surface and transpiration were increased resulting in the lowering of the atmospheric temperature.

Matjakin's (1952) experimental works in which he studied changes in air temperature at two heights, 1m and 0.25m, in the protected and open fields reported a much higher air temperature nearest the ground and greater deviation of about $3^{o}C$ at 0.25m compared with the temperature at corresponding height in the open field. He reported the maximum diurnal range of temperature occuring in the leeward was in accordance with the location of minimum wind speed.

Van Eimern (1954) investigated the shelter effect on temperature under different shade conditions. At two different locations without shade he found higher air temperature immediately behind the belt (2H) than in the open field, but at a third location under shade, the air temperature at 2H was lower than in the open field. He then concluded that shelterbelt increases air temperature near the lee edge of belts but any variation that might occur could be possible through differing shades and ground covering.

2.3 EFFECT OF SHELTERBELT ON SOIL TEMPERATURE.

The effect of shelterbelt on soil temperature was investigated by Eimern (1954). In addition to soil temperature, he also measured wind speed in the sheltered and unsheltered sides of the belt. He observed higher soil temperature within the lee side than in the windward side.

The higher temperature coincided with the areas of reduced wind speed. The low soil temperature in the shaded portion behind the belt despite the considerable reduction in wind speed made him conclude that the changing of soil temperature by wind reduction is limited and uneven depending on the degree of ground's covering by the canopy.

Johnson (1957) examined the effect of shelterbelt on soil temperature as a function of wind velocity; this observation followed results of simultaneous measurements of soil temperature to a depth 20cm and wind speed to a height of 1m. in which he found higher mean soil temperature in areas of low wind velocity and vice versa.

Fuss (1956) believed that on sunny days the irregular shadows cast by the plants could eclipse the influence of wind protection on soil temperature. He therefore took measurements on cloudy days. His results revealed higher soil temperature mostly within the lee side than in the open field. It was further noticed that the time of the day had much influence on soil temperature. He noted an increase of 0.8°C at 5cm. soil depth within a distance of 0.8H from the belt as compared to 0.3°C at 5cm soil depth in the open field. He found the effect greater at 3.00 p.m. than at 8.00 a.m. He however found the effect difficult to isolate from each other because of the effect of soil moisture and wind speed on soil temperature. The literature on the effect of shelterbelt on soil temperature is extensive. Studies by Steubing (1952), Burnaski et al (1955), Aslying (1958), Kaiser (1960), Staple and Lahane (1955) and Papamek (1981) all showed a clear dependence of soil temperature on wind reduction.

2.4 THE EFFECT OF SHELTERBELT ON SOIL MOISTURE AND EVAPORATION

The effectiveness of shelterbelts in conserving soil moisture through reduction in wind speed and evaporation has been studied by many investigators.

Maran et al (1950) in their study of the effect of shelterbelt on moisture storage in a loamy soil reported increase in soil moisture up to the middle of the field between consecutive belts, compared with the open field. They however observed lower soil moisture content closer to the belt which they attributed to the tree roots which tend to extract soil water in that zone. Beyond the middle of the field, moisture storage was found to be equal to those in the open field.

Gagarin (1949) working on the rate of soil water losses through evaporation in the protected and open field reported higher rate of moisture losses by transpiration and evaporation in unsheltered areas than in the sheltered zone. Within the lee, he found 50 and 30 percent decrease in evaporation at 2H and 15H respectively. At about the centre of the field the reduction was 10 per cent. From the percentage decrease in evaporation at various points he deduced that the rate of moisture loss depends on the proximity of those points to the shelterbelt.

Van Eimern (1954, 1964, 1958) however found no shelter effect on soil moisture in a loamy soil with oat, and he ascribed the increase in yield to wind protection. However, data obtained during periods of little but evenly spread rains showed a greater decrease in soil moisture at greater distances from the belt.

Walker (1951) used evaporation and wind reduction data as yard-sticks for assessing the shelter effect on soil moisture. From his experimental results he reported that the greatest reduction in evaporation occurred within a distance of 10H and 15H from the belt.

Golubeva (1941) in a similar study with belts 200m apart and 7m high found 40 percent decrease in evaporation at 2H, (14m) and 10% at 10H (70m). At about the centre of the field, he found 5% decrease while the corresponding reductions in wind speed were 60%, 25% and 15% respectively. This observations agree with the conclusions of Walker that shelterbelt influences wind speed more than evaporation.

Wilusz (1958) used air and soil temperature data to deduce the possible position of soil moisture. With higher air and soil temperature figures obtained near the edge of the belt, he predicted a corresponding higher rate of moisture losses irrespective of the amount of reduction in wind velocity in that zone.

The observation by Gorsenin (1960) on soil moisture at various distances from a wooded belt indicated a positive effect of shelterbelt on soil moisture retention to a soil depth of 1m extending to 10H away from belt. He however thought that the shelter effect would more vividly be expressed at the upper soil layers than at greater depths because of the water table level which might influence the soil moisture condition.

2.5 THE EFFECT OF SHELTERBELT ON CROP YIELD

The early reports on the effect of wind protection on the yield of agricultural crops, particularly in Russia, U.S.A. and Denmark is given by Smith (1929), Naegeli (1941) and Anderson (1952). Generally yield increases vary from region to region, they also depend on the types of crops and soils.

Bender (1955) carried out yield measurement over 3 years on light sandy soil planted with a variety of crops. The mean yield for the three years for each variety of crop in the sheltered zone was found to be higher than in the unsheltered area for the three successive years with yield increase of 180, 186 and 220 percent respectively. Hence he concluded that shelterbelt increase yield of crops with age of the belt.

Many other yield experiments have always produced favourable results owing to shelter effect. The reported increase in crop yield owing to shelterbelt in wheat, barley, oats and hay on heavy soil of the Netherlands by Jonker (1954) and on clay soil in the Rhineland by Kaiser (1957) followed a curve similar to that of soil moisture content. This indicates that crop yield is better in areas of higher soil moisture content.

Comprehensive survey, taking into account results found by other authors has been made by George (1960). He found that although the crops and soil types on which individual investigators worked vary, yield results are generally better in the sheltered zone than in the unsheltered areas.

Within the lee side, varying trends in the yield were observed in which some results showed crop yield following similar curve to wind reduction, greatest immediately behind the belt and becoming less farther away, while other reports show low yield close to the belt, followed by highest yield and then decreasing further away. He further observed that in every sheltered field there are areas in which crop yield is reduced by shading and by competition of roots.

From these reports, it becomes an acceptable fact that shelterbelts protect the adjacent area against the extremes of weather and improve yield of crops. However the extent of protection and nature of the yield vary with climates. It is necessary to determine the extent to which shelterbelt can reduce the adverse weather conditions and increase crop yield in the arid and semi arid zones in Nigeria. The present study investigates the extent of shelter effect on wind speed, air and soil temperatures, soil moisture and yield of crops in Dambatta.

3. MATERIALS AND METHOD

3.1 Site and Layout

This experiment started in July 1980 and ended in June 1981. The two sites selected are about three and half kilometers apart and are located in Dambatta about seventy kilometers north of Kano State. The sites consisted of farmlands between two parallel shelterbelts and open farmlands on the windward side exposed to adverse weather conditions. The shelterbelt lines run in an east to west direction at an angle of 45°. to the prevailing winds. The tree species for the shelterbelts are Eucalyptus camaldulensis. with average height of 10m. The shelterbelts are of medium density. The degree of density or permeability of the shelterbelt was visually determined by the percentage ratio of the perforated area of the belt to the total vertical area of the belt. On the basis of this, a belt could be very dense, dense, medium dense or porous depending on percentage ratio of the perforations to the vertical area of the belt. The distance between two parallel belts is 300m, while the width of each block of belt is about 30m. In each of the sites the land has very gentle slope of about 2%.

The soil of each site is sandy, deep and well drained (Table 1). The farmlands had been abandoned by the farmers prior to the establishment of the shelterbelts because of constant poor crop yield, soil moisture problem and exposure of the soil to wind erosion.

The site layout is given in Fig. 1. There are four columns of blocks of farmland 12m apart running perpendicular to the belts with 5m gaps at the edge of each belt and six rows of blocks of farmland parallel to the belts.

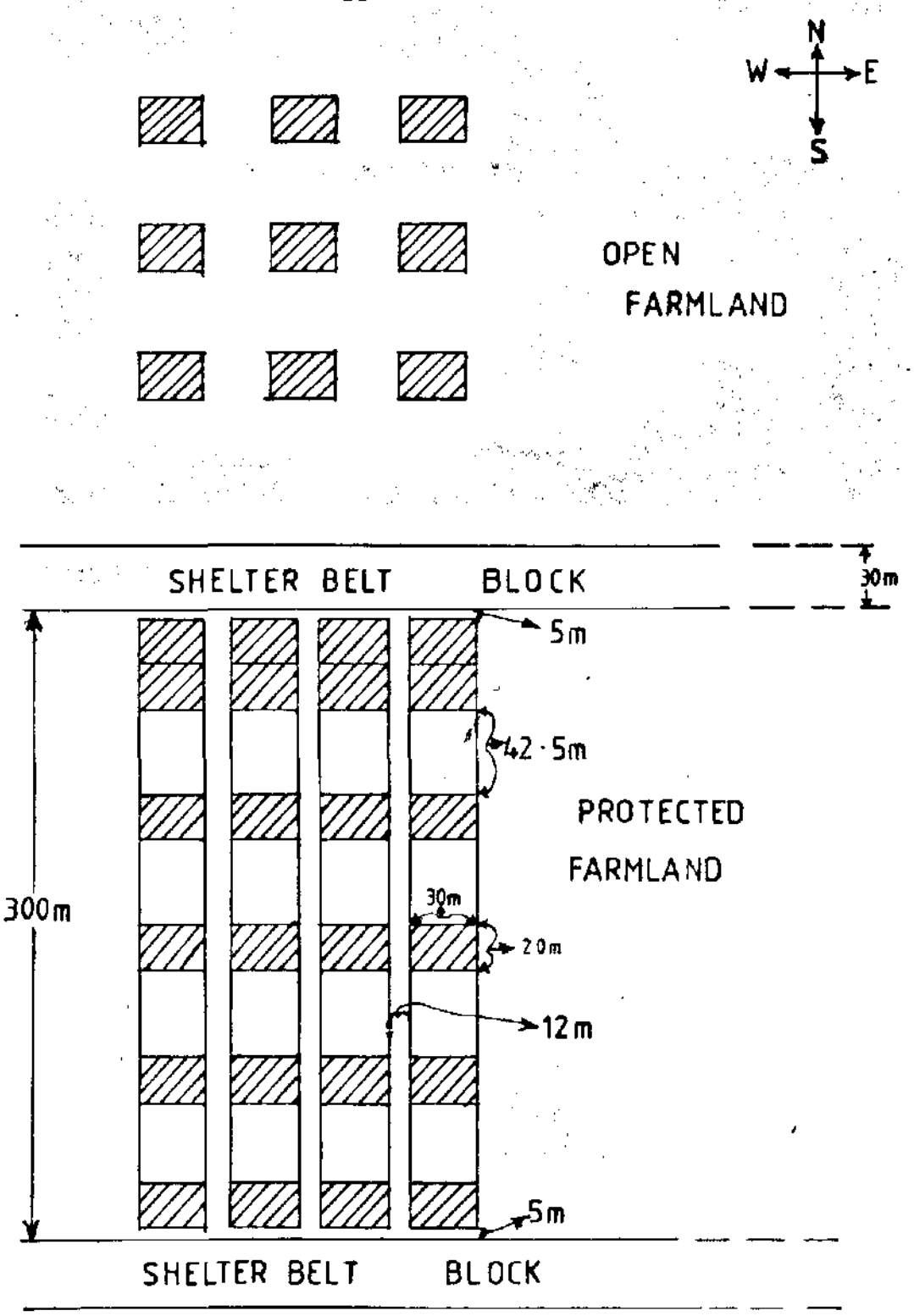


Fig-1 Layout of field experiment. Sampling Plot

Scale: 1cm = 30m

Two of the rows are joined together while the other four are in singles 42.5m apart. The shaded portions in fig.1 are planted and sampling plots 30m x 20m (600 sq.m). This brought the area of each protected and unprotected for investigation to about 1.98 hectares.

Cultivation followed normal practice with ridges perpendicular to the belt. In this process of ridging, organic matter residues of beans and groundnuts from the previous years harvest were incorporated into the soil. Superphosphate was also applied by broadcast prior to ridging at the rate of 100kg. per hectare. Millet was sown first week in July when the rains had sufficiently wet the soil profile. Sowing distances were 45cm apart along rows and 90cm between rows. Depth of sowing differ according to soil types; it ranges from 2cm for heavy soils to 4cm for sandy soil (Egharevba 1981). For Dambatta sandy soil, the sowing depth was 4cm. Because of the short coleoptile and the small food reserve in the millet seed, it should not be sown very deep (Egharevba 1981). Yield was determined by weighing the grains from each plot separately and then converting into kilograms per hectare.

3.2 FIELD MEASUREMENT.

The field measurements included the following:

3.2.1 Wind Speed

Wind speed measurements using anemometers (0-1000m range and capacity of 1-15m/sec) were taken one meter above the ground surface at distances of 20, 40, 100, 150, 200 and 300m from the shelterbelt on the leeward side and 100 and 200m on the windward side.

Measurements were done three times weekly at 11.00 a.m. and 2.00 p.m. The figures obtained were expressed in meters per second and the percentage reduction of wind speed in the protected side of the belt was calculated from the data.

3.2.2. Air Temperature

Air temperature was measured with thermometers in a screen located at the same height and at the same distances from the belt as the windspeed measurement. Measurements were taken three times weekly at 8.00 a.m. 12 noon and 3.00 p.m. throughout the period of observation. The monthly mean air temperature was calculated by adding the data obtained for each time of the day and dividing this sum by the number of times measurement were recorded for that month. Annual mean was calculated by summing up the monthly mean and dividing by the number of months.

3.2.3. Soil Temperature

Soil thermometers (mecury-in-glass model with a right angled bend in the stem with graduation range 0-50°C) were used for this purpose. These instruments were installed at depths of 5cm, 10cm, and 30cm at distances of 20, 40, 100, 150, 200 and 300m from the belt in the protected side of the farmland and 100 and 200m in the open field. Method of observation was similar to that described for air temperature. The monthly mean soil temperature was calculated as described for the air temperature. This measurement was carried our throughout the growing season and after harvest.

3.3. LABORATORY ANALYSIS

3.3.1. Determination of particle size distribution

The silt and clay percentages of the soil samples from Dambatta were by pipette method based on Stoke's Law, Black (1965). Although this method is time consuming it was the only method whose equipments were available to me at the time of the experiment. The removal of the soil fraction whose diameters were above 200 microns was by wet sieving. Organic matter content was initially destroyed by adding an appropriate volume of 20% H_2O_2 and by leaving the mixture overnight. Colloidal despersion was achieved by the addition of a 5% solution of calgon (sodium hexameta - phosphate). A volume of 20ml per 20g. of air dried soil was used. The various soil fractions were expressed as percentages of weight of soil sample.

3.3.2. Soil moisture content

Soil moisture was determined to the depth of 100cm by gravimetric method. The samples were usually collected at 9.00a.m. by means of hand auger at interval depths of 10, 20, 40, 60, 80, and 100cm in two replicates and then taken to the laboratory in covered and numbered alluminium cans for determination of water content. This was carried out twice weekly throughout the period of the experiment. The moist samples were weighed at first and oven-dried at a temperature of 105°C to constant weight. From the weights of moist and oven-dried samples, water content was calculated as a perdentage of oven dry weight. Moisture storage was calculated by multiplying the percentage water content by the bulk density to

obtain the volumetric moisture content which was multiplied by the soil depth to get the moisture storage of a given soil depth. By summing up the products the amount of water stored in the profile to a given depth was obtained.

3.3.3 Bulk Density

The bulk density was determined with an undisturbed soil sample to depths of 10, 20, 40, 60, 80, and 100cm obtained by pushing soil corer of known volume into the soil body of a profile pit and bringing it out again filled with soil. This was replicated twice to get the average bulk density for each depth. In this practice, care was taken not to compress the soil or alter the soil particle arrangements. To avoid any imbalance in the volume of soil and the internal volume of the corer, the two ends of the soil corer were trimmed to the brim by means of a knife. The samples were oven dried at a temperature of 105°C and then weighed. The bulk density was expressed as the weight of oven-dried soil in relation to its volume.

3.3.4 Porosity Calculation

The percentage pore space was calculated from the bulk density and particle density (2.65 g/cm^3) figures, using the equation:

$$\% \text{ pore space} = \left(1 - \frac{\text{Bulk density}}{\text{Particle density}}\right) \times 100.$$

4. RESULTS AND DISCUSSION

4.1 Particle Size Distribution

Table 1 shows the particle size distribution, bulk density and total porosity as a function of soil depth.

The Particle size distribution data show that the soil profile is mostly free from stones and gravel. The soil at site I has a texture ranging from coarse sand at the upper layers to loamy fine sand down the lower horizon. In contrast, the texture of the soil at site II is loamy fine sand throughout the profile.

4.2 Bulk Density

It is observed from the data in Table I that there is a gradual increase in the bulk density values with profile depth. The average values in site I range from 1.51 g/cm^3 at the top soil to 1.54 g/cm^3 at greater depths, for site II the corresponding range is 1.51 to 1.56 g/cm^3. On the whole, the bulk density values of the above range showed that the soil was not compact but provided good conditions for aeration and root development.

4.3 Total Porosity

Values of total porosity of soil are of importance since they determine how much soil space is occupied jointly by water and air. The values also indicate the degree of soil compaction.

The total porosity calculated from the bulk density and particle density (2.65 g/cm^3) values showed that the average values decreased with soil depth, ranging from 43.0% to 41.1% in site II and 43.0 - 41.9% in site I. From the above data, it can be said that both sites have virtually identical physical characteristics, except the anomalous 83% coarse sand in 0-10cm in site I.

TABLE I. Some Physical Properties of Dambatta Shelterbelt Soils

Soil depth (cm)	Clay	Silt	Fine sand	Coarse sand	Textural class	Average bulk density	Average Porosity (% V/V)
	<0.002	0.002 -0.02 (% W/W)	0.02-0.2	0.2 - 2mm		(g/cm ^{3})	
				Site I			
0-10	5	3	9	83	CS	1.51	43.0
10-20	7	4	45	44	S	1.52	42.6
20-40	7	8	55	30	LFS	1.54	41.9
40-60	6	7	57	30	LFS	1.52	42.6
60-80	8	7	56	30	LFS	1.54	41.9
80-100	8	7	56	29	LFS	1.54	41.9
				Site II			
0-10	5	11	51	32	LFS	1.51	43.0
10-20	7	10	53	30	LFS	1.53	42.4
20-40	8	8	54	30	LFS	1.54	41.9
40-60	7	10	54	39	LFS	1.54	41.9
60-80	6	11	55	28	LFS	1.54	41.9
80-100	6	11	56	27	LFS	1.56	41.1

CS = Coarse sand

S = Sand

LFS = Loamy Fine Sand

The reason for this could be attributed to the slope of the site into which coarse sand have been washed by erosion or by force of gravity.

4.4 Wind Speed

Wind speed data in the open and protected sides and mean percentage wind speed reduction at the lee side of the shelterbelt at site II are given in Table 2. Similar data for site I are shown in appendix 2. The data indicate that reduction in wind speed extends to a distance of 300m from the belt throughout the period of observation with mean percentage reduction of 5.3%. At 20m and 40m wind speed reduction was 20.9% and 20% respectively and showed that the percentage wind reduction decreased with increased distance from the belt (fig. 2).

Wind speed in the open field always exceeded those between belts. For example in January (Table 2) wind with a velocity of 4.49m/sec from the open field has reduced to 3.50 and 3.56m/sec at 20m and 40m respectively on lee side. However at 300m wind speed has again increased to 4.30m/sec.

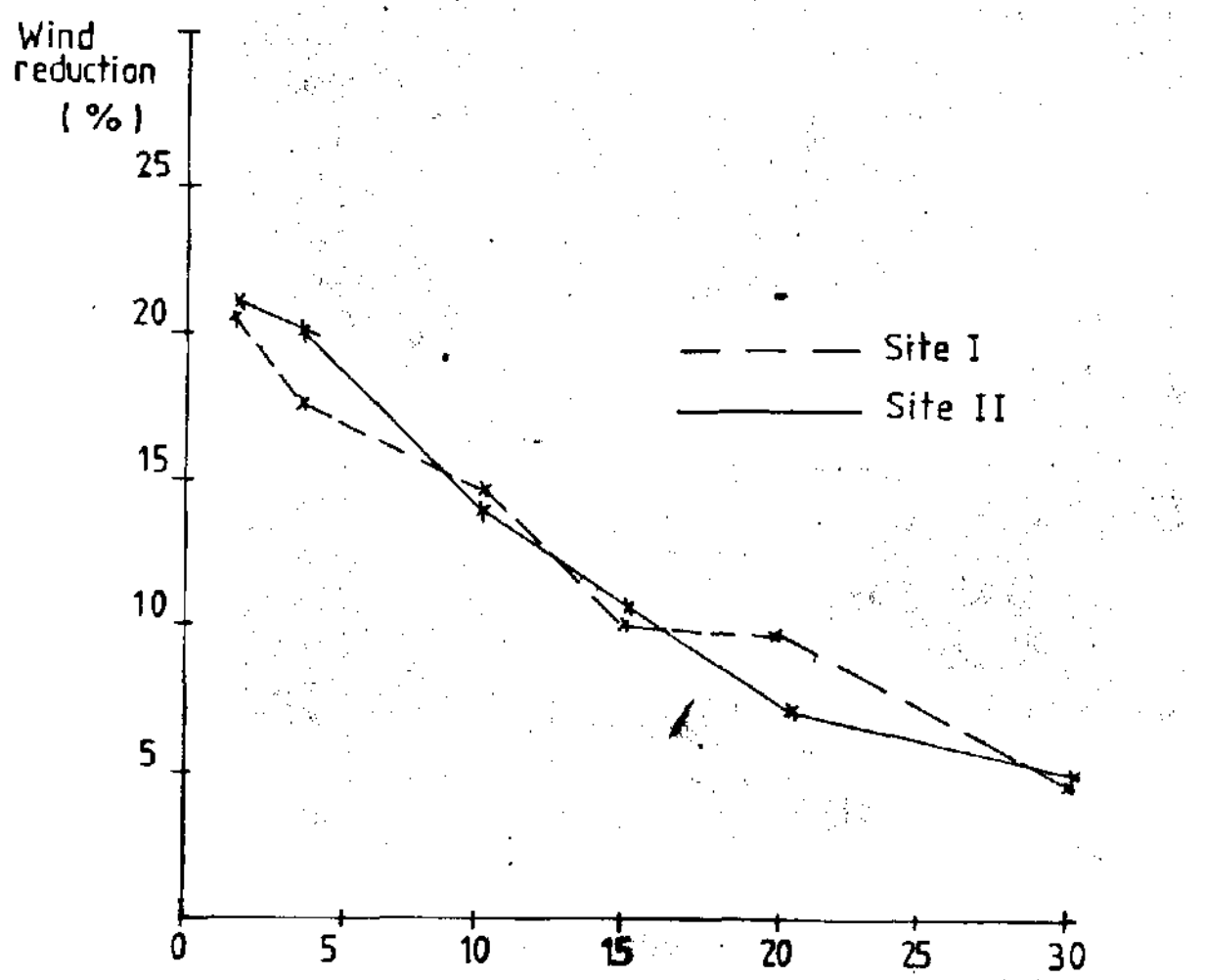
This situation occurred regularly in all observations, thus indicating that immediately behind the shelterbelt, wind speed was reduced to a minimum and then started to regain speed with increased distances leeward. The effectiveness of this belt in reducing wind speed extended beyond 15H (150m), where the mean percentage wind reduction was on the average 10.6%. This result is fairly in agreement with the findings of Naegeli (1946) who established 10% as the limit below which shelterbelt was of no effect in reducing wind speed.

TABLE 2. Effect of Shelterbelt on Wind Speed (m/sec.) and (%) wind reduction in the open and protected farmland at Dambatta.

Site II

Period	Open	Distances (m) in the Protected Area											
	200m	20m Prot.	% Red.	40m Prot.	% Red.	100m Prot.	% Red.	150m Prot.	% Red.	200m Prot.	% Red.	300m Prot.	% Red.
Aug.	2.64	2.13	19.30	2.15	18.70	2.26	14.40	2.31	12.50	2.43	7.95	2.50	5.30
Sept.	1.99	1.59	20.10	1.60	19.60	1.68	15.60	1.74	12.60	1.84	7.50	1.90	8.70
Oct.	3.63	2.77	23.70	2.88	20.40	3.10	14.60	3.18	12.40	3.32	8.50	3.41	6.10
Nov.	2.61	2.10	19.50	2.11	18.40	2.25	13.80	2.39	8.40	-	-	-	-
Dec.	-	-	-	-	-	-	-	-	-	-	-	-	-
Jan.	4.49	3.50	22.10	3.56	20.70	3.80	15.4	3.94	12.30	4.18	6.90	4.30	4.20
Feb.	2.14	1.73	19.20	1.75	18.70	1.82	14.9	1.94	9.30	2.00	6.50	2.04	4.70
March	4.65	3.65	21.50	3.63	21.90	3.99	14.28	4.19	9.90	4.32	7.10	4.42	5.00
April	3.25	2.55	21.50	2.64	21.20	2.89	11.10	2.60	9.40	2.65	6.20	3.09	4.90
May	2.87	2.26	21.30	2.27	20.90	2.55	11.20	2.60	9.40	2.65	7.70	2.70	4.88
June	3.01	2.39	20.60	2.42	19.60	2.50	16.90	2.66	11.60	2.80	6.97	2.89	3.98
Mean Percentage			20.9		20.0		14.2		10.6		7.3		5.3

Prot. = Protected
% Red. = Percentage Reduction



Fig·2 Mean wind speed reduction in percent at different distances from the belt in sites I & II.

He also recorded 30 and 10% wind reduction at the leeward side at 1H and 18H respectively, and less than 10% at distances beyond 18H. Although the effectiveness of this belt appears to end a little beyond 150m, the tendency for the wind at any point after that to reach speeds in excess of or equal to those in the open field is counteracted by the presence of the next shelterbelt line, thus the wind speed in the lee side was always less than those in the open field.

The range (difference between the highest and lowest values) in percentage reduction in wind speed at any time of the year at each of the points in the leeward is calculated to be about 1.7% for 20m, 1.3% for 40m, 3.1% for 100m, 3.5% for 150m 0.8% for 200m and 1.4% for 300m. These low range values are indications of constant effectiveness of the shelterbelt throughout the period of observation irrespective of the initial open field wind speed.

4.5 Air Temperature

The monthly and annual mean air temperature in the open and protected areas of the shelterbelt at site I are given in Table 3. Higher monthly mean temperature was recorded at a distance of 20m on the leeward side with values ranging from 30.9°C in January to 40.9°C in April. Comparative figures for open field are 30.0°C and 39.8°C respectively. In the lee side of the belt temperature decreased with increased distances from the belt, but in most cases the temperature at the extreme lee side evens out with those in the open field.

From 20m to about 100m, a steady annual mean temperature decrease was observed but beyond 100m changes in temperature were not much. Thus 100m could be regarded as the limit to which the shelterbelt can effectively influence the air temperature under the experimental conditions.

The annual mean air temperature in the open farmland is seen to be the least with a temperature of 34.4°C compared with those in the lee side of the belt, which range from 34.6°C to 35.6°C. In some individual months no differences are observed between the temperature in the protected and open fields beyond 40m. For example, in August (Table 3) the mean temperature at site I in the open field was 32.1°C compared with 32°C from 150m to 300m in the lee side. The trend is similar for most other months. These data indicate that the influence of the shelterbelt on air temperature, although still detected at 300m but very faintly, is limited to a short distance, about 100m behind the belt.

This observation is comparable to results of previous experiments by Goldberg (1951), and Burnacki (1952) in which higher air temperatures were observed within the lee side of the belt than in the open.

In site II (Table 4) a slightly different trend in air temperature occurred with lower annual mean temperature from 100-300m, than in the open field while the highest temperature of 34.7°C was recorded at 20m corresponding to the zone of greatest wind reduction.

TABLE 3 Monthly Mean Maximum Air Temperature (^{o}C) on the leeward and windward sides of the belt at Dambatta - Kano State.

Site I

Period	OPEN	Distances from the belt (m) PROTECTED 20	40	100	150	200	300
July	32.1	33.5	33.3	32.9	32.2	32.1	32.0
Aug.	32.1	33.9	33.4	32.8	32.0	32.1	32.0
Sept.	33.2	34.1	33.8	33.0	33.2	33.1	33.3
Oct.	34.3	35.0	34.7	34.4	34.4	34.2	34.2
Nov.	34.3	35.2	34.9	34.5	34.6	34.3	34.4
Dec.	32.7	33.5	33.3	33.3	33.0	33.0	33.1
Jan.	30.0	30.9	30.7	30.0	29.6	30.1	30.1
Feb.	31.0	31.8	31.6	31.1	31.0	31.2	31.2
March	37.1	38.0	37.5	37.5	37.2	37.2	37.2
April	39.8	40.9	40.2	39.7	39.7	39.5	39.5
May	38.2	39.0	38.9	38.4	38.1	38.2	38.3
June	34.3	35.1	34.8	34.3	34.3	34.1	34.2
Annual Mean	34.4	35.6	35.3	34.8	34.6	34.6	34.7

4.6 Soil Temperature

Details of the monthly mean soil temperature at various distances from the belt in the sheltered and open farmland in sites and II are given in the appendix 3 and 4 respectively and a summary of them including changes in soil temperature at different times of the day are given in Tables 5 and 6 respectively.

It was observed from Table 5 (site I) that the soil temperature in the sheltered area was slightly higher than soil temperature in the open farmland by less than $1^{o}C$ and this higher temperature was mostly observed within distances of 20m and 40m behind the belt.

Within the lee side it was also noted that differences in temperature occurred from one distance to the other with greatest value occuring immediately behind the belt and then decreased with subsequent distances away. The higher temperature immediately behind the belt could be a result of low soil moisture content caused by the roots of the trees and bushes which are in active competition for soil water in that zone. In addition, the reduced wind speed could also be a contributory factor. The low soil temperature in the open field was probably due to increased wind speed.

Changes in soil temperature at different times of the day was also examined at different distances from the belt. It was observed that the temperature of the soil at 5cm depth on a typical day during the growing season increased with time of the day at various distances from the belt; for example at 20m the value was

TABLE 4 Monthly mean Maximum Air Temperatures (^{o}C) in the leeward and windward sides of the belt at Dambatta - Kano State.

Site II

	OPEN	Distances from the belt (m) in protected area					
Period	200m	20	40	100	150	200	300
July	31.8	32.3	31.8	31.6	31.4	31.5	31.4
Aug.	31.8	32.3	31.8	31.6	31.2	31.4	31.3
Sept.	32.9	33.4	33.0	32.7	32.6	32.1	32.4
Oct.	33.8	34.5	33.6	33.2	32.8	33.0	33.2
Nov.	33.8	34.5	34.0	33.6	33.6	33.0	33.4
Dec.	32.0	32.8	32.1	31.8	31.8	31.9	32.0
Jan.	30.9	31.6	31.2	31.0	30.8	30.9	31.0
Feb.	34.3	34.9	34.5	34.0	33.7	34.1	34.0
March	36.9	37.8	37.0	36.8	36.6	36.6	36.4
April	38.2	39.6	38.7	38.3	38.1	37.8	38.4
May	37.8	38.4	37.9	37.8	37.8	37.2	37.5
June	33.8	34.5	34.0	33.6	33.7	33.7	33.4
Annual Mean	34.0	34.7	34.1	33.8	33.67	33.6	33.7

TABLE 5 Annual Mean Soil Temperature (°C) in the Open and Protected areas at 5cm., 10cm and 30cm Soil depths at Sites I and II

Site I

Soil depth (cm)	OPEN		Distances from the belt (m) in Protected sides					
	200	100	20	40	100	150	200	300
5	35.0	35.1	35.7	35.4	35.2	35.1	35.1	35.2
10	33.2	33.3	33.9	33.5	33.2	33.3	33.2	33.3
30	28.7	28.9	29.3	29.1	28.9	28.8	28.9	28.9

Site II

5	35.8	36.0	36.6	36.3	36.0	35.9	36.0	35.9
10	34.5	34.4	34.9	34.6	34.5	34.5	34.4	34.5
30	29.6	29.5	30.0	31.0	31.5	29.4	29.4	29.5

TABLE 6 Soil temperature (^{o}C) with time of the day at different soil depths and distances from the belt on 16/7/80

Soil depth (cm)	Distance from belt (m)	Time of the day		
		8 am.	12 pm.	3 p.m.
5	20	28.4	36.4	38.7
10	20	26.8	34.2	35.6
30	20	25.4	28.8	28.9
5	40	27.9	36.0	38.0
10	40	26.5	34.0	35.0
30	40	25.0	26.5	26.7
5	100	27.4	35.5	38.0
10	100	26.0	33.8	34.0
30	100	25.0	26.4	26.7

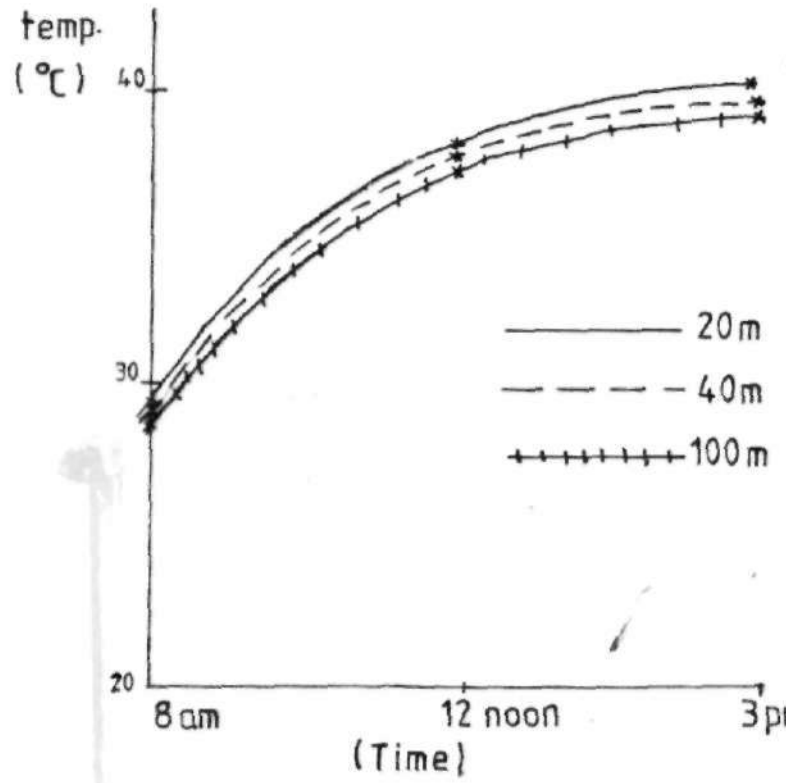
28.4°C at 8.00 a.m. and increased to 36.0°C by 12 noon. At about 3.00 p.m. the maximum temperature for the day (38.7°C) was recorded. The temperatures at 40m and 100m, which are slightly lower than the temperature at 20m follow a similar pattern. For a depth of 10cm, the difference between the temperature at 20 and 40m was smaller than the temperature at 100m. The trend of temperature increase with time of the day is common to different distances from the belt and to different soil depths.

On a typical day during the dry season (Fig.3) the changes in soil temperature with time of the day at the depth of 5cm follow the same trend as that obtained during the growing season. At 10cm depth (Fig.4) soil temperature increased with time of the day, but the shelter effect on soil temperature with distance from the belt at this depth was negligible. The reason could depend on the degree of the cloudiness of the atmosphere during the day of the measurements.

The decreasing soil temperature with soil depth (Table 6) was observed at all distances from the belt but this is independent of shelter effect.

4.7 Soil Moisture Regime

Comprehensive data on mean values of soil moisture content to a depth of 100cm. for sites I and II are given in Appendix 5-8 and a summary of their soil moisture storage is given in Table 7.



Fig·3 Shelter effect on 5cm depth soil temperature at different time of the day and at different distances (m) from the belt on 28/11/80.

From July to September, during the rains when the soil profile is constantly recharged, there is almost uniformity in moisture storage for both open and sheltered areas, and so the shelter effect on soil moisture during the period was negligible.

The shelter effect become visible at the start of the dry season when from October to December, the soil moisture storage droped from 299.7mm in July to September to 100mm in October to December in the open field. In the sheltered zone the reduction was from 291.4 to 122.9, 300 to 143.4, 310.5 to 122.9 and 313.3 to 113.4mm at 20, 40, 100 and 150m respectively (site II). The effect of the belt continued to unfold as dry season advanced from January to March with moisture storage amounting to 70.7 and 89.4mm at 20m and 40m respectively compared with 49.7mm of water in the open field and 58.3, 52,6, 50.9 and 49.8mm at 100, 150, 200 and 300m respectively.

Within the protected side, soil moisture storage was not only higher close to the belt but also the rate at which soil moisture depleted was lower than farther away from the belt. This result is in agreement with the results of Mastinskaya (1953) and Razumov (1959) who in their soil moisture measurements found higher values nearer the belt, while further away, values approximated to those in the open field.

Although the absolute values of moisture stored do not vary very widely, the influence of the belt on moisture storage is still noticeable at a distance of 40m from the belt, where the amount of moisture stored to a depth of 100cm was 89.4mm compared to 49.7mm for the open field.

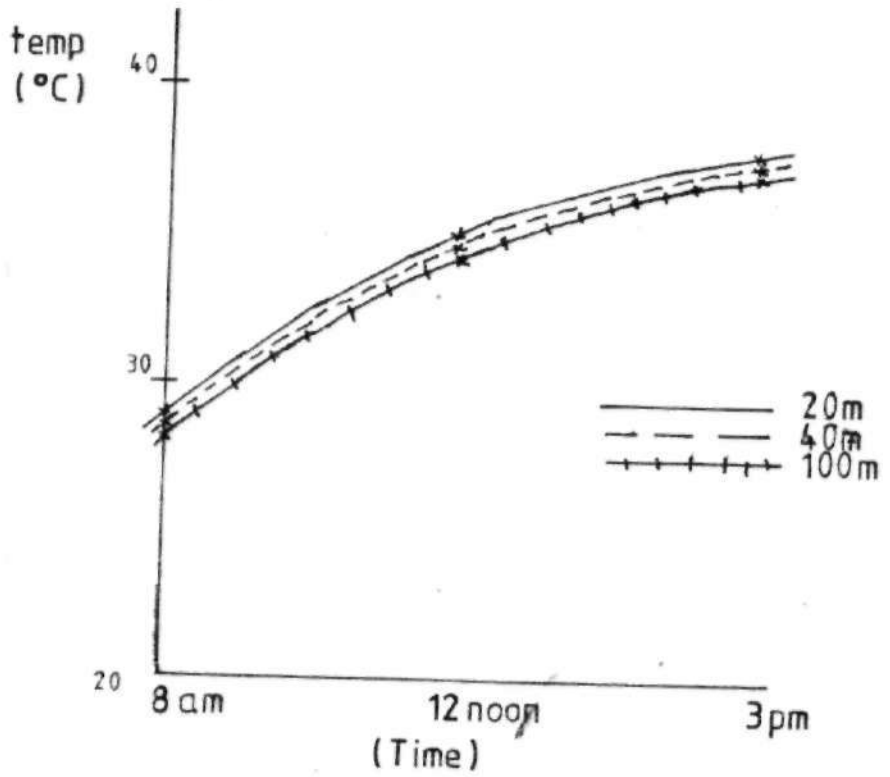


Fig. 4 Shelter effect on 10 cm soil depth temperature at different time of the day and at different distances (m) from the belt on 28/11/80.

TABLE 7 Quarterly soil moisture storage (mm) for the 0-100cm depth at various distances from the belt at Sites I and II.

Site I

Period	OPEN	Distances from belt (m) in protected side					
	200	20	40	100	150	200	300
July-Sept.	283.0	276.8	289.8	274.9	278.5	268.3	270.9
Oct.-Dec.	110.7	128.0	150.2	120.2	114.4	109.7	110.8
Jan-March	60.0	72.0	83.6	70.0	68.4	60.4	61.5
April-June	48.2	35.5	51.0	40.6	50.0	37.0	49.4
Total Storage	502.0	512.3	574.6	512.4	511.3	475.4	492.6

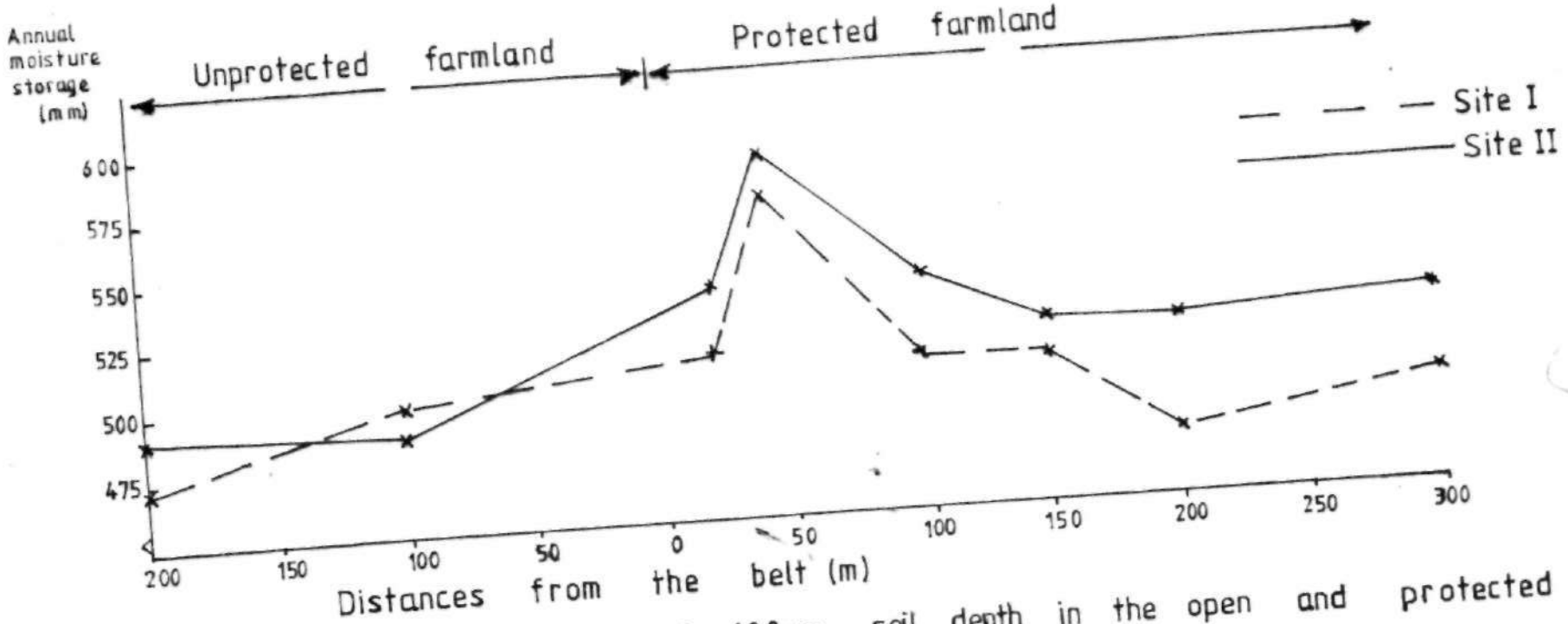
Site II

July-Sept.	299.7	291.4	300.7	310.5	310.5	313.3	309.8
Oct-Dec.	100.0	122.9	143.4	122.9	111.8	113.4	115.3
Jan-March	49.7	70.7	89.4	58.3	52.6	50.9	49.8
April-June	42.6	55.1	55.2	49.9	46.0	43.1	45.9
Total Storage (mm)	491.2	540.1	588.7	541.6	520.9	520.7	520.8

The amount of water conserved at 40m is higher than at 20m despite the reduced wind speed to a minimum at 20m. The reason for this descrepancy could be due to competition for soil water by the tree roots. Secondly, the soil and air temperatures are higher near the lee edge of the belt and might result in evaporation of soil water. Fig 5 shows the total soil moisture storage at 100cm depth in open and protected farmlands in sites I and II. The curve in site II shows higher soil moisture content than in site I. It is also seen that the pattern of moisture distribution in both sites is not quite identical, but the reason for this is not clear and needs further investigation. It is however, important to note that moisture storage in each of the sites is more in the protected than in the unprotected side. On the basis of this, it can be said that the shelterbelts have protective effect on soil moisture storage through reduction in wind speed.

4.8 Yield of Millet

Yield results in the protected and unprotected areas on sites I and II are generally low and are given in Tables 8 and 9 respectively. It can be seen from the tables that yields in the sheltered zones are better than in the open fields. From Table 9, it is observed that yields varied with distance from the belt on the leeward side. The mean yield (67.3 kg/ha) at 40m was significantly higher (at 5% level) than the mean yields at other points. This was followed by the yield (64.0 kg/ha) at 20m which was significantly higher than the yields at 150, 200 and 300m but was at par with the yield (61.3 kg/ha) at 100m.



Fig·5 Soil moisture storage at 0 - 100 cm soil depth in the open and protected farmland on site I & II

TABLE 8 The Yield of Millet (kg/ha) in the protected and open Farmlands.

Site I

Listances from Belt (m)	Open farmland						Protected farmland					
	R1	R2	R3	R4	ΣR	R̄	R1	R2	R3	R4	ΣR	R̄
20	-	-	-	-	-	-	69.3	69.8	66.5	67.2	272.8	68.2
40	-	-	-	-	-	-	73.3	75.2	68.9	69.4	286.8	71.7
100	58.7	57.8	60.8	66.1	243.4	60.8	70.1	66.3	69.3	65.8	271.5	67.9
150	-	-	-	-	-	-	63.3	64.2	65.7	68.1	261.3	65.3
200	58.8	65.9	58.0	58.4	241.1	60.3	63.0	60.9	64.4	63.8	252.1	63.0
300	54.6	57.1	53.9	58.7	224.3	56.1	60.7	61.2	59.6	60.1	241.6	60.4
	LSD 5% = 5.2 Ranking = 100 200 300						LSD 5% = 3.0 Ranking = 40 20 100 150 200 300					

R1-4 = Replicates 1 - 4

ΣR = Summation of Yields in the replicates

R̄ = Mean Yield

Ranking = No significant differences in yield between numbers joined with continuous line.

TABLE 9 The Yield of Millet (Kg/ha) in the protected and open farmland.

Site II

Distances from Belt (m)	Open farmland						Protected farmland					
	R1	R2	R3	R4	ΣR	$\bar{R}$	R1	R2	R3	R4	ΣR	$\bar{R}$
20	-	-	-	-	-	-	65.7	65.5	66.7	60.1	255.9	63.9
40	-	-	-	-	-	-	69.5	70.7	65.8	63.2	269.2	67.3
100	57.5	48.3	52.1	55.2	213.1	53.28	64.3	60.0	59.6	61.8	245.7	61.3
150	-	-	-	-	-	-	59.8	59.8	60.0	58.4	238.0	59.5
200	53.7	48.8	47.0	53.0	202.5	50.0	57.9	56.3	39.6	55.9	229.7	57.4
300	47.9	45.6	50.3	41.2	185.0	46.3	56.9	55.6	55.7	56.6	224.8	56.2
	LSD 5% = 6.9 Ranking = 100 200 300						LSD 5% = 3.25 Ranking = 40 20 100 150 200 300					

R1-4 = Replicates 1 - 4

ΣR = Summation of Yield in the replicates

$\bar{R}$ = Mean Yield

Ranking = No significant difference in yield between numbers joined with continuous line.

The low yield generally in both sites could be attributed either to poor quality of the local variety of seeds used for the sowing or disease and insect attacks.

The differences between the yield at 40m and the yields at 20, 100, 150, 200 and 300m were 3.3, 3.9, 7.8, 9.8 and 11.1 kg/ha respectively, thus indicating that yield decreases as distance from the belt increases. This yield trend appears to be similar to that of percentage wind speed reduction. The low yield at 20m immediately behind the belt in this work, could be due to competition between the trees and the crop for soil water and the higher air and soil temperature near the edge of the belt which may not have favoured growth and development of the crop. There is no shading effect on yield at 20m. The orientation of the belts (east to west direction) and the direction of sun's movement (east to west) do not provide shade up to 20m.

Shelter effect on crop yield is a bit bigger at site II than site I. The reasons for this could be due to more soil water storage and greater wind reduction on site II than site I. Wind speed reduction can improve yield also by reducing evaporation from the plant.

The mean yield at 4H (40m) on site I (table 8) was significantly different (1% level) from the mean yield at other distances leeward. The yield in the open farmland was low and the trend in yield was found to have decreased with increased distances from the belt leeward.

Although the yield is generally very poor, below 100 kg/ha there is evidence of bigger yield in the protected areas than in the open fields. It is therefore probable that the main effect of shelterbelt on yield is mostly due to reduced wind speed and minimized losses of the stored soil moisture.

5. SUMMARY AND CONCLUSION

The work has investigated possible effects of shelterbelt on wind speed, soil moisture, soil temperature and yield of millet.

The major effect of shelterbelt is that of surface wind speed reduction. Other changes such as changes in air and soil temperature, soil water content, plant growth and yield are mostly consequences of the reduced wind speed.

Under the experimental condition, the minimum wind speed occurred at 20m immediately behind the belt and the distance between the point of minimum wind speed and the point where wind started to re-establish speed again was relatively small, less than 20m.

The percentage wind reduction at a particular point behind the belt remains almost the same at any time of the measurement, irrespective of the initial open field wind speed.

The extent to which shelterbelt influenced wind speed was not the same proportion as it influenced soil moisture, air and soil temperature, but the shelter effect on these variables is mostly felt closer to the belt than further away. For wind speed shelter effect extended to 15H (150m) and the percentage reduction at that point was about 10% on average. For soil and air temperatures, the shelter effect terminated at 10H (100m). The influence of shelterbelt on soil moisture retention was mostly shown during the dry season when soil moisture storage in the open field was seen to be lower than those in the sheltered zone especially at 2H (20m) and 4H (40m).

The decrease in soil temperature with increase in soil depth and the increase in soil moisture with increasing soil depth are independent of shelter effect, but the overall increase in soil moisture and soil temperature in areas of reduced wind speed was a consequence of shelter effect.

The uniformity in soil moisture storage in the open and sheltered sides of the farmland during the growing season (July-September) was expected to reflect on yield accordingly. But suprisingly, differences in yield occurred despite the uniform moisture content observed on all fields. The reason for this is not clear, but it could be suggested that wind speed reduction in the sheltered area might have reduced evaporation from the plants thus decreasing moisture stress. It is therefore thought that the yield increase in the sheltered zone was due to greater wind protection resulting in lower rate of losses of the stored soil moisture.

In conclusion, any future work on this problem should include the measurements of atmospheric humidity, leaf water potential and the amount of precipitation within the problem area. Consideration should be given to the choice of experimental sites of different soil types in each of which inter-croping system could be used in view of the fact that yield of crops varies not only with climate but also with soil and plants themselves.

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APPENDIX 1 Some physical properties of Dambatta shelterbelt soils as function of distance from belt.

Soil depth (cm.)	Clay	Silt.	Fine sand	Coarse sand	Textural class	Bulk Density ($g.cm^3$)						Total Porosity (%)					
	<0.002	0.002-0.02	0.02-0.2 (%W/W)	0.2-2mm		2H	4H	10H	15H	20H	30H	2H	4H	10H	15H	20H	30H
						Site I											
0-10	5	3	9	83	CS	1.52	1.50	1.51	1.50	1.51	1.53	42.6	43.4	43.0	41.5	43.0	42.3
10-20	7	4	45	44	S	1.52	1.54	1.50	1.50	1.54	1.53	42.6	42.6	43.4	41.1	41.9	42.3
20-40	7	8	55	30	LFS	1.54	1.55	1.55	1.54	1.52	1.54	41.9	42.3	41.5	41.8	42.6	41.9
40-60	6	7	57	30	LFS	1.54	1.53	1.52	1.52	1.52	1.50	41.9	42.3	42.6	42.6	42.6	42.6
60-80	8	7	56	30	LFS	1.53	1.54	1.54	1.54	1.53	1.54	42.6	42.6	41.9	41.9	42.0	41.1
80-100	8	7	56	29	LFS	1.54	1.54	1.53	1.54	1.54	1.56	41.9	41.9	42.3	41.9	42.6	41.1
						Site II											
0-10	5	11	51	32	LFS	1.52	1.51	1.52	1.50	1.50	1.51	42.6	43.2	42.6	43.4	43.4	43.0
10-20	7	10	53	30	LFS	1.53	1.52	1.54	1.52	1.53	1.52	42.3	42.6	41.9	42.6	42.3	42.6
20-40	8	8	54	30	LFS	1.53	1.53	1.54	1.54	1.53	1.54	42.3	42.3	41.9	41.9	42.3	41.9
40-60	7	10	54	29	LFS	1.55	1.54	1.53	1.53	1.54	1.52	41.5	41.9	42.3	42.3	41.9	42.3
60-80	6	11	55	28	LFS	1.56	1.52	1.53	1.54	1.54	1.53	41.10	42.6	42.3	41.9	41.9	42.3
80-100	6	11	56	27	LFS	1.56	1.54	1.54	1.56	1.54	1.54	41.10	41.9	41.9	41.1	41.9	41.9

Assumed Particle Density 2.65 g/cc
LFS = Loamy Fine Sand
CS = Coarse Sand

APPENDIX 2 Effect of Shelterbelt on wind speed (m/sec) and percentage (%) wind reduction in the open and protected farmland at Dambatta.

Period	OPEN	Site: PROTECTED											
		2H Prot	% Red.	4H Prot.	% Red.	10H Prot.	% Red.	15H Prot.	% Red.	20H Prot.	% Red.	30H Prot.	% Red.
Aug.	2.76	2.17	21.4	2.26	18.1	2.31	16	2.48	10.14	2.55	7.60	2.63	4.71
Sept.	2.56	2.00	21.87	2.13	16.79	2.23	12.8	2.48	10.9	2.34	8.5	2.41	5.8
Oct.	3.61	2.92	19.11	2.98	17.5	3.02	16.3	3.18	11.9	3.31	8.3	3.40	5.8
Nov.	3.00	2.40	20.0	2.47	17.7	2.53	15.7	2.65	11.7	1.72	9.3	2.81	6.3
Dec.	-	-	-	-	-	-	-	-	-	-	-	-	-
Jan.	4.34	3.44	20.74	3.53	18.70	3.61	16.82	3.89	10.36	3.94	9.2	4.16	4.14
Feb.	2.78	2.18	21.58	2.23	19.78	2.34	15.82	2.43	12.58	2.51	9.71	2.66	4.32
March	4.24	3.36	20.75	3.42	19.34	3.59	15.33	3.81	10.14	3.93	7.31	4.11	3.06
April	2.96	2.28	22.9	2.35	20.6	2.47	16.55	2.68	9.45	2.69	9.12	7.78	6.08
May	2.57	2.07	19.46	2.18	15.18	2.26	12.06	2.38	7.39	2.39	7.00	2.43	5.44
June	3.39	2.76	18.58	2.97	12.38	3.10	11.21	3.01	8.55	3.17	6.48	3.20	5.60
Mean Percent Wind Reduction		20.7		17.6		14.9		10.3		9.8		5.1	

Prot. = Protected
% Red. = Percentage Reduction
H = Distance from belt in multiples of tree height. 1 tree height = 10m

APPENDIX 3 Mean Monthly soil Temperature (°C) in sheltered and open farmland at Dambata, Kano State. 1980/81.

Site I

Time	Soil depth (cm)	Open Field				Sheltered Area			
		1OH	2OH	2H	4H	1OH	15H	2OH	3OH
July 1980	5cm	33.3	33.1	33.9	33.7	33.4	33.3	33.3	33.5
	10cm	32.2	32.1	32.7	32.4	32.2	32.2	32.1	32.2
	30cm	27.7	27.5	28.5	28.2	28.0	28.0	28.1	28.1
Aug. 1980	5cm	33.0	32.9	34.3	33.9	33.5	33.0	33.4	33.6
	10cm	32.1	32.0	33.4	32.8	32.4	32.3	32.3	32.4
	30cm	29.3	29.1	29.9	29.8	29.6	29.4	29.6	29.6
Sept. 1980	5cm	34.3	34.2	34.9	34.7	34.4	34.4	34.4	34.6
	10cm	33.4	33.3	33.8	33.6	33.4	33.5	33.4	33.2
	30cm	29.2	29.1	29.7	29.5	29.4	29.2	29.2	29.0
Oct. 1980	5cm	34.9	34.7	35.6	35.2	34.8	34.8	34.6	34.7
	10cm	34.1	34.0	34.6	34.3	33.3	34.0	34.0	34.0
	30cm	28.0	28.1	28.8	28.6	28.0	28.1	28.0	28.2

H = Distance from belt in multiples of tree height. (: tree height = 10m)

APPENDIX 4. Mean monthly soil temperature (°C) in protected and open farmland at Dambatta, Kano State. 1980/81.

Site II.

Period	Soil depth (cm)	Open Field		Protected Area					
		10H	20H.	2H	4H	10H.	15H.	20H.	30H.
July 1980	10	32.4	32.1	32.6	32.3	32.4	32.4	32.3	32.4
	30	28.8	28.7	29.4	29.2	29.3	29.2	29.9	29.9
Aug. 1980	10	32.0	31.9	32.7	32.5	32.5	32.4	32.2	32.4
	30	28.3	28.4	28.5	28.3	28.5	28.4	28.1	28.3
Sept 1980	10	32.5	32.3	33.8	33.6	33.2	33.2	32.6	32.7
	30	29.4	29.2	29.5	29.5	29.2	29.2	29.1	29.2
Oct. 1980	10	33.9	33.6	34.6	34.2	34.4	34.3	34.6	34.5
	30	28.8	28.9	30.1	30.0	29.6	29.4	29.5	29.6
Nov. 1980	10	34.2	34.0	34.8	34.3	34.1	34.0	34.0	34.0
	30	29.4	29.4	30.0	29.8	29.6	29.4	29.4	29.2
Dec. 1980	-	-	-	-	-	-	-	-	-

H = Distance from belt in multiples of tree height. (1 tree hight = 10m).

Mean Monthly soil temperature (^{o}C) on site II contd.

Period	Soil depth (cm)	Open field				Protected Area			
		1OH	2OH	2H	4H	1OH	15H	2OH	3OH
Jan. 1981	10	32.1	32.00	32.90	32.70	32.56	32.40	32.40	32.45
	30	29.4	29.50	29.50	29.31	29.24	29.20	29.0	29.5
Feb. 1981	10	34.7	34.00	34.90	34.67	34.51	34.60	34.50	34.60
	30	29.6	29.70	30.10	29.61	29.80	29.52	29.49	29.50
March 1981	10	37.0	36.13	37.25	37.25	27.15	37.20	37.11	37.15
	30	30.40	30.45	30.60	30.50	30.50	30.30	30.60	30.60
April 1981	10	38.60	37.90	38.25	38.0	38.0	37.89	37.90	38.0
	30	30.40	30.50	30.60	30.60	39.65	29.55	29.60	29.48
May 1981	10	37.40	37.70	37.70	37.68	37.50	37.28	37.30	37.20
	30	30.40	30.40	30.40	30.40	30.25	30.20	30.25	30.25
June 1981	10	34.00	39.50	33.80	33.71	33.45	33.45	33.58	33.70
	30	29.60	30.20	29.80	29.80	29.63	29.30	29.40	29.60

H = Distance from belt in multiples of tree height. (1 tree height = 10m)

APPENDIX 5 Effect of shelterbelt on soil moisture at protected Site I Dambatta, Kano State. 1980/81

Site I

Distances from belt (m)	Soil Depth (cm)	July	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	March	April	May	June	Total mc % per soil layer	Total water storage per soil layer	Total water storage (mm) per meter soil depth
20	0–10	6.88	5.07	4.66	1.44	1.01	0.54	0.60	0.50	0.42	0.31	0.27	0.48	22.60	3.44	
	10–20	8.27	5.67	4.32	1.60	1.29	0.85	0.84	0.68	.60	0.51	0.48	0.56	26.28	4.02	
	20–40	8.56	5.79	5.69	2.47	2.27	1.88	0.97	0.88	.71	0.64	0.59	0.62	30.96	9.47	
	40–60	7.73	6.00	5.74	2.77	2.66	1.90	1.80	1.67	1.38	1.10	0.99	1.24	35.04	10.86	512.3
	60–80	8.40	5.73	4.98	2.36	2.06	2.05	1.83	1.54	1.42	1.21	1.08	1.18	33.84	10.60	
	80–100	9.39	6.42	6.09	3.90	2.89	2.48	2.02	1.84	1.62	1.52	1.45	1.46	41.16	12.84	
40	0–10	6.93	4.84	4.24	1.66	1.41	0.78	0.69	0.57	0.50	0.50	0.44	0.65	23.28	3.54	
	10–20	8.74	6.02	5.66	2.62	2.35	0.91	0.83	0.73	0.63	0.63	0.61	0.67	30.48	4.70	
	20–40	9.89	5.96	5.05	3.19	2.30	1.72	1.62	.89	0.81	0.80	0.78	0.84	33.84	10.42	
	40–60	9.09	5.56	5.06	2.90	2.74	2.04	1.88	1.68	1.59	1.52	1.46	1.48	37.08	11.42	574.6
	60–80	9.94	5.69	6.28	3.73	2.83	2.23	2.08	1.93	1.92	1.86	1.81	1.89	42.24	12.93	
	80–100	9.99	7.97	6.46	3.88	3.08	3.87	3.71	2.09	2.02	2.00	1.86	1.94	46.92	14.45	

Effect of shelterbelt on soil moisture on site I contd.

Distances from belt (m)	Soil depth (cm)	July mc %	Aug. mc %	Sept mc %	Oct. mc %	Nov. mc %	Dec. mc %	Jan. mc %	Feb. mc %	March mc %	April mc %	May mc %	June mc %	Total mc % per soil layer	Total water storage per soil layer	To wa st (m pe me so de
200	0-10	6.03	4.16	4.32	1.03	1.00	0.59	0.52	0.42	0.40	0.32	0.30	0.49	19.56	2.93	
	10-20	8.11	4.69	4.45	2.08	1.78	0.61	0.60	0.50	0.49	0.40	0.37	0.54	24.6	3.76	
	20-40	8.62	6.33	4.45	1.99	1.81	1.04	0.90	0.80	0.72	0.66	0.61	0.96	28.92	8.85	4
	40-60	9.00	6.15	4.58	1.89	1.73	1.41	1.24	1.04	0.99	0.90	0.84	1.22	30.96	9.52	47
	60-80	8.96	6.66	5.16	2.49	1.89	1.66	1.32	1.14	1.10	1.00	0.96	1.34	33.72	10.39	
	80-100	9.94	7.01	5.82	2.99	2.61	2.26	1.89	1.49	1.39	1.11	1.05	1.66	39.24	12.09	
300	0-10	5.55	4.00	3.98	1.24	1.01	0.62	0.61	0.36	0.30	0.29	0.24	0.45	18.72	2.83	
	10-20	7.66	4.87	4.50	2.04	1.44	0.66	0.65	0.58	0.56	0.51	0.48	0.53	24.48	3.72	
	20-40	8.74	6.17	5.13	2.89	1.81	1.40	0.97	0.89	0.73	0.66	0.61	0.83	30.84	9.50	4
	40-60	9.34	5.88	4.92	2.85	2.23	1.83	1.41	1.33	1.03	0.89	0.82	1.23	33.72	10.25	49
	60-80	9.62	5.11	4.67	2.82	2.20	1.93	1.61	1.59	1.42	1.04	1.00	1.48	34.44	10.54	
	80-100	10.11	6.35	6.60	3.01	2.36	2.07	1.98	1.89	1.69	1.36	1.34	1.61	40.32	12.42	

APPENDIX 6 Mean monthly soil moisture percent in the open area of Dambatta, Kano State. 1980/81

Site I

Distances from	Soil depth (cm)	July mc %	Aug. mc %	Sept mc %	Oct. mc %	Nov. mc %	Dec. mc %	Jan. mc %	Feb. mc %	March mc %	April mc %	May mc %	June mc %	Total mc % per soil layer	Total water storage per soil layer (cm)	Total water storage (mm) per meter soil depth
100	0-10	7.10	5.16	3.94	1.00	0.73	0.51	0.12	0.20	0.18	0.17	0.15	0.29	19.56	2.97	
	10-20	8.24	5.86	4.49	1.07	0.98	0.87	0.63	0.60	0.57	0.55	0.51	0.62	24.99	3.79	
	20-40	7.94	6.44	4.67	1.65	1.34	1.06	0.91	0.75	0.70	0.62	0.61	0.70	27.39	8.43	
	40-60	8.65	5.13	5.51	2.44	2.12	2.00	0.98	0.92	0.86	0.80	0.76	0.85	31.02	9.55	486.6m
	60-80	9.55	6.74	5.73	2.63	2.43	2.41	1.49	1.43	1.33	1.23	1.09	1.18	37.24	11.39	
	80-100	9.78	6.94	5.78	2.97	2.82	2.08	1.88	1.70	1.71	1.65	1.60	1.71	40.62	12.51	
200	0-10	6.86	4.65	3.66	0.98	0.86	0.49	0.33	0.31	0.26	0.21	0.19	0.32	19.12	2.90	
	10-20	8.44	6.76	5.11	1.13	1.06	0.94	0.74	0.57	0.53	0.49	0.47	0.61	26.85	4.08	
	20-40	8.59	6.34	5.32	1.42	1.21	1.10	0.87	0.81	0.78	0.70	0.68	0.75	28.57	8.79	
	40-60	9.48	5.93	4.91	2.14	1.98	1.13	1.01	0.98	0.90	0.83	0.80	0.83	30.92	9.02	491.-
	60-80	9.50	6.75	6.13	2.54	2.42	1.16	1.22	1.15	1.00	1.00	0.98	1.11	34.96	10.69	
	80-100	9.66	7.40	6.17	3.16	2.61	2.00	1.83	1.77	1.74	1.60	1.55	1.62	41.11	12.66	

APPENDIX 7 Effect of shelterbelt on soil moisture at the protected site II

Distances from bolt (m)	Soil depth (cm)	July mc %	Aug. mc %	Sept mc %	Oct. mc %	Nov. mc %	Dec. mc %	Jan. mc %	Feb. mc %	March mc %	April mc %	May mc %	June mc %	Total mc % per soil layer	Total water storage per soil layer (cm)	Total water storage (mm) per meter soil depth
20	0-10	7.34	6.00	4.54	2.11	0.99	0.85	0.62	0.44	0.28	0.28	0.28	0.43	24.17	3.67	
	10-20	8.63	6.56	5.58	2.92	1.09	0.93	0.80	0.65	0.49	0.45	0.43	0.54	29.07	4.42	
	20-40	8.57	5.98	5.72	3.04	2.52	1.92	1.08	0.78	0.70	0.67	0.60	0.75	32.35	9.96	540.5mm
	40-60	7.37	5.98	5.16	3.75	2.83	1.89	1.63	1.55	1.50	1.38	1.25	1.29	35.58	10.95	
	60-80	8.00	6.85	5.75	3.85	2.63	2.55	1.67	1.58	1.37	1.30	1.26	1.28	38.09	11.66	
	80-100	9.93	7.43	6.98	4.10	2.88	2.67	2.09	1.88	1.44	1.40	1.33	1.36	43.49	13.39	
40	0-10	7.41	5.83	4.96	2.51	1.00	0.90	0.62	0.47	0.28	0.27	0.27	0.46	24.98	3,75	
	10-20	8.33	6.87	5.23	2.90	2.56	2.11	0.87	0.81	0.79	0.68	0.65	0.71	32.41	5.01	
	20-40	9.82	6.77	6.00	2.92	2.60	2.2	1.20	1.00	0.95	0.84	0.81	0.88	35.99	11.16	588.7mm
	40-60	8.80	6.90	5.64	3.07	2.82	2.64	1.77	1.44	1.04	1.00	0.97	1.01	36.92	11.30	
	60-80	9.24	6.75	5.63	3.36	2.98	2.77	1.97	1.88	1.80	1.67	1.64	1.69	41.38	12.75	
	80-100	9.74	7.89	6.99	4.98	3.82	3.02	2.36	2.09	2.00	1.98	1.78	1.79	48.44	14.90	

Shelter effect on soil moisture on site II contd.

Distances from belt (m)	Soil depth (cm)	July mc %	Aug. mc %	Sept mc %	Oct. mc %	Nov. mc %	Dec. mc %	Jan. mc %	Feb. mc %	March mc %	April mc %	May mc %	June mc %	Total mc % per soil layer	Total water storage per soil layer (cm)	Total water storage (mm) per meter soil depth
100	0-10	7.01	5.83	4.77	1.92	0.89	0.80	0.59	0.34	0.22	0.20	0.17	0.38	23.2	3.50	
	10-20	8.17	5.93	5.39	2.96	1.44	1.09	0.52	0.54	0.47	0.45	0.40	0.52	27.88	4.20	
	20-40	9.23	5.87	5.24	2.74	2.20	1.11	0.84	0.64	0.67	0.65	0.61	0.67	30.47	9.45	540.9mm
	40-60	9.16	6.29	5.14	2.87	2.11	1.89	1.40	1.35	1.30	1.22	1.02	1.06	34.83	10.60	
	60-80	9.93	6.43	5.33	3.43	3.0	2.97	1.63	1.57	1.71	1.59	1.43	1.46	40.48	12.47	
	80-100	10.53	8.70	5.47	4.80	3.09	2.49	2.00	1.89	1.82	1.71	1.36	1.48	45.35	13.88	
150	0-10	7.00	5.95	4.70	1.80	0.80	0.71	0.56	0.32	0.14	0.12	0.11	0.39	22.60	3.40	
	10-20	8.40	5.98	5.04	1.84	1.01	0.94	0.71	0.55	0.32	0.30	0.27	0.47	25.83	3.87	
	20-40	8.51	5.99	5.41	2.48	1.93	1.90	0.95	0.60	0.57	0.54	0.51	0.54	29.93	9.22	
	40-60	8.99	6.61	5.80	2.82	2.09	1.80	1.48	1.44	1.24	1.20	1.16	1.20	35.63	10.83	522.9mm
	60-80	9.65	6.73	5.77	2.86	2.20	1.88	1.59	1.44	1.31	1.28	1.25	1.27	37.95	11.69	
	80-100	10.12	7.23	6.31	4.09	2.64	2.47	2.15	1.80	1.84	1.71	1.38	1.39	43.13	13.28	

Shelter effect on soil moisture on site II contd.

Distances from belt (m)	Soil depth (cm)	July mc %	Aug. mc %	Sept mc %	Oct. mc %	Nov. mc %	Dec. mc %	Jan. mc %	Feb. mc %	March mc %	April mc %	May mc %	June mc %	Total mc % per soil layer	Total water storage per soil layer (cm)	Total water storage (mm) per meter soil depth
200	0-10	7.37	5.82	4.44	1.90	0.84	0.88	0.54	0.30	0.12	0.11	0.11	0.39	22.22	3.40	
	10-20	8.41	5.93	5.57	1.88	0.99	0.98	0.70	0.49	0.37	0.36	0.35	0.46	26.52	4.08	
	20-40	7.77	6.71	5.80	2.08	1.86	1.08	0.86	0.54	0.51	0.50	0.42	0.47	28.71	8.73	520.7mm
	40-60	9.14	6.84	6,57	2.09	2.08	1.69	1.49	1.31	1.13	1.13	1.09	1.11	35.69	10.85	
	60-80	9.31	6.90	5.99	2.67	2.09	1.69	1.54	1.46	1.26	1.24	1.21	1.27	36.65	11.20	
	80-100	9.24	7.87	6.59	4.59	2.89	2.64	2.28	2.11	1.80	1.70	1.55	1.58	44.84	13.81	
300	0-10	7.37	5.81	4.88	1.81	.81	0.79	0.49	0.32	0.19	0.17	0.16	0.45	23.31	3.57	
	10-20	8.65	5.93	5.00	2.02	1.08	0.94	0.74	0.48	0.46	0.43	0.40	0.46	26.59	4.07	
	20-40	8.39	6.21	5.00	2.64	1.61	1.09	0.82	0.58	0.55	0.51	0.49	0.53	28.43	8.75	520.8mm
	40-60	9.11	5.98	5.74	2.76	1.97	1.62	1.60	1.55	1.42	1.40	1.32	1.34	35.81	10.75	
	60-80	9.15	6.55	5.80	3.00	2.94	1.87	1.44	1.58	1.53	1.48	1.41	1.42	38.17	11.75	
	80-100	9.43	6.57	5.92	4.47	2.70	2.19	1.97	2.00	1.88	1.80	1.64	1.65	42.22	13.18	

APPENDIX 8 Mean monthly soil moisture percent by weight in the open Area.

Site II

Distances from belt (m)	Soil depth (cm	July mc %	Aug. mc %	Sept mc %	Oct. mc %	Nov. mc %	Dec. mc %	Jan. mc %	Feb. mc %	March mc %	April mc %	May mc %	June mc %	Total mc % per soil layer	Total water storage per soil layer (cm)	Total water storage (mm) per meter soil depth
100	0-10	7.34	6.25	4.18	0.94	0.77	0.44	0.29	0.24	0.20	0.15	0.14	0.26	21.20	3.22	
	10-20	8.87	6.90	5.44	0.99	0.91	0.82	0.77	0.72	0.67	0.60	0.58	0.69	27.96	4.27	
	20-40	10.24	5.75	5.63	1.45	1.27	0.97	0.77	0.74	0.70	0.67	0.64	0.70	29.61	8.06	
	40-60	9.50	6.81	5.69	2.69	2.33	1.23	0.93	0.88	0.81	0.74	0.70	0.73	33.04	10.24	475.2mm
	60-80	10.22	6.81	5.51	2.73	2.40	1.81	1.42	1.41	1.09	0.99	0.96	1.12	36.47	10.37	
	80-100	10.22	6.95	5.73	2.77	2.61	2.54	2.22	2.21	2.00	1.89	1.80	1.91	42.85	11.36	
200	0-10	7.76	5.46	4.81	1.28	0.86	0.58	0.39	0.31	0.26	0.22	0.19	0.28	22.40	3.40	
	10-20	9.24	7.11	4.97	1.86	0.95	0.76	0.71	0.63	0.58	0.56	0.50	0.63	28.50	4.06	
	20-40	8.66	7.0	5.23	1.81	1.73	1.52	1.35	1.28	1.18	1.02	1.00	1.26	30.04	9.19	
	40-60	9.11	6.26	5.62	2.17	2.06	1.98	1.76	1.52	1.43	1.33	1.21	1.41	33.87	10.11	502.0mm
	60-80	10.40	6.74	5.62	2.25	2.16	2.10	2.00	1.96	1.90	1.68	1.61	1.87	38.29	11.17	
	80-100	10.61	6.92	6.18	2.91	2.64	2.58	2.43	2.30	2.00	1.98	1.90	2.16	40.61	12.27	