EFFECT OF WIND ON THE EARLY GROWTH OF FIVE TREE SPECIES PLANTED TO FORM WINDBREAKS IN NORTHERN AUSTRALIA

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SUN, D. & DICKINSON, G.R. 1995.. Effect of wind on the early growth of five tree species planted to form windbreaks in northern Australia. The effect of wind on the early growth of five species, *Callistemon salignus, Eucalyptus microcorys, E. tessellaris, E. torelliana* and *Melaleuca armillaris*, planted to form windbreaks was examined on two adjacent paddocks on the tropical Atherton Tablelands of north Australia. In Paddock 1, trees of *C. salignus, E. microcorys* and *M. armillaris*, were grown with and without wind protection using *Zea mays* (maize). In Paddock 2, trees of all the five species mentioned above were planted with three treatments: (1) protected by an existing perimeter mound for 12 months, (2) protected by *Zea mays* (maize) for 5 months and (3) no wind protection. Wind direction and speed were measured at intervals of two hours at both the open and the perimeter mound sheltered areas using an automatic weather station. Tree angle to ground, height and crown size were measured at age 5 months on Paddock 1 and at age 12 months on Paddock 2. Trees of each species leaned over as a result of wind. Tree height and crown growth were significantly reduced by wind. Trees protected for 12 months suffered less wind effect than trees protected for only the first 5 months. *E. microcorys* appeared to be more susceptible to wind damage than the other species studied. It is suggested that resistance to wind damage should be an important criterion for species selection when forming windbreaks in windy areas.

Key words: Wind - tree growth - windbreaks - northern Australia

SUN, D. & DICKINSON, G.R. 1995. Kesan angin pada pertumbuhan awal lima spesies yang ditanam sebagai ladang angin di Australia Utara. Kesan angin pada pertumbuhan awal lima spesies, *Callistemon salignus, Eucalyptus microcorys, E. tessellaris, E. torelliana* dan *Melaleuca armillaris*, yang ditanam sebagai ladang angin dikaji pada dua paddock yang bersebelahan di Atherton Tablelands, Australia Utara . Di Paddock 1, Pokok-pokok *C. salignus, E. microcorys* dan *M. armillaris* ditanam tanpa pelindungan angin dan dengan *Zea mays* (jagung) sebagai pelindung angin. Di Paddock 2, kesemua lima spesies tersebut ditanam dengan tiga rawatan: (1) dilindung dengan sempadan anak bukit yang wujud selama 12 bulan, (2) dilindung dengan *Zea mays* (jagung) selama 5 bulan dan (3) tiada perlindungan dari angin. Arah dan kelajuan angin diukur pada jarak waktu dua jam di kawasan-kawasan terbuka dan yang dilindungi anak bukit dengan mengguna-kan stesen cuaca automatik. Sudut pokok ke tanah, tinggi dan saiz silara telah diukur ketika berumur 5 bulan pada Paddock 1 dan ketika berumur 12 bulan pada Paddock 2. Pokok-pokok daripada setiap spesies condong disebabkan oleh angin. Ketinggian pokok dan pertumbuhan silara berkurangan dengan ketaranya oleh angin. Pokok-pokok yang dilindungi selama 12 bulan mengalami kesan angin yang kurang daripada pokok-pokok yang hanya dilindungi selama 5 bulan yang pertama. *E.microcorys* lebih mudah mengalami kesesakan angin dari spesies-spesies lain yang dikaji. Dicadangkan bahawa tentangan terhadap kerosakan akibat dari angin patut dijadikan kriteria penting untuk pemilihan spesies apabila mengadakan ladang angin di kawasan-kawasan berangin.

Introduction

It has long been recognized that wind causes destructive physical damage to crops (Bates 1917, Caborn 1957, Frank *et al.* 1974, Kort 1988). Plant physiological processes are also influenced by wind which causes changes in plant surface temperature and light interception by altering leaf angle (Grace 1988). Many studies have shown that windbreaks can provide protection from wind effect and benefit crop growth (Marshall 1967, Sturrock 1981, Kort 1988, Sun & Dickinson 1994) and livestock production (Reid & Bird 1990). Because of these benefits, windbreaks have become an important component in agroforestry systems in many areas of the world (Bagley 1988).

Apart from windbreak design and assessment of windbreak effect on crops using existing windbreaks, planting and establishment of windbreaks have also attracted some attention. Most of the establishment studies dealt with species selection, site preparation, weed control and water requirements during the establishment period (Sheikh 1988). In Australia, particularly in tropical north Australia, few studies have been carried out to examine the effect of wind on the establishment of the windbreak itself. Wind which causes damage to crops may also affect young tree growth and thus affect the establishment of windbreaks. It is important to know the extent of these effects and to develop techniques to improve windbreak establishment in windy areas. In addition, most species selection work has concentrated on the suitabilities of species for specific regions, growth rate and morphology. Information of species resistance to wind damage may be also important for successful establishment of windbreaks.

The work reported here was undertaken to add further to our understanding of windbreak establishment when subjected to wind and tree species resistance to wind damage.

Materials and methods

Species utilised

Callistemon salignus, *Eucalyptus microcorys*, *E. tessellaris*, *E. torelliana* and *Melaleuca armillaris* were used to form the wind breaks and their mean heights when planted were 0.52 (±0.02) m, 0.46 (±0.02) m, 0.35 (±0.01) m, 0.48 (±0.01) m and 0.51 (±0.01) m respectively. These species were chosen because they are suitable for the region (Boland *et al.* 1984). An existing perimeter mound and *Zea mays* (maize) were used to provide wind protection for the early growth of these tree species.

Study site

The study was carried out on two adjoining paddocks, 5 km from Atherton on the Atherton Tablelands of north Australia. The size of Paddock 1 was 800 × 800 m and that of Paddock 2 was 760 × 800 m (Figure 1). Both paddocks which have a red krasnozem soil, have long been used to grow crops of maize, peanuts and potatoes in rotation. On Paddock 2, there was an existing perimeter mound with grasses growing along the southern boundary. The average combined height of mound and grasses was 2.5 m. The land was flat and fully exposed to winds. According to the weather record from a local weather station, the prevailing wind in this area comes from the southeast (SE) and is strong throughout the year.

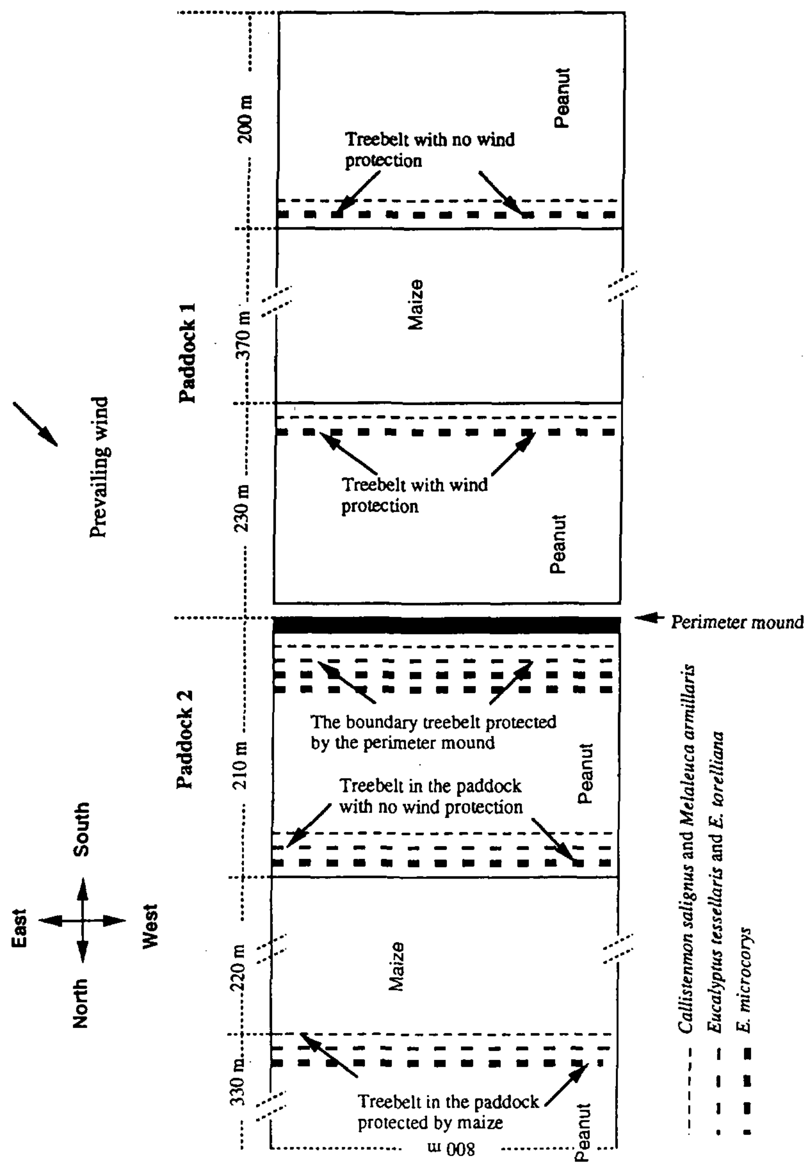

Figure 1. The layout of the experiment on both Paddocks 1 and 2

Experimental design

Paddock 1. Maize seeds were sown on a 800 m long, 370 m wide rectangular site within Paddock 1 on 15 December 1991. On both the south and north sides of the maize paddock, two windbreaks running east/west (Figure 1) were planted on 9 January 1992. Ideally the maize and windbreaks would be perpendicular to the direction of the prevailing wind (Oboho & Nwoboshi 1991), but the current study was limited by the shape of the available paddocks.

Both windbreaks consisted of two rows of trees, one row of *C. salignus* and *M. armillaris* on the windward side and one row of *E. microcorys* on the leeward side (Figure 1). The distance between the rows was 2 m. Within each windbreak, *C. salignus* and *M. armillaris* were planted in sequence with five trees each with a 2 m intra-row spacing while *E. microcorys* was planted 4 m apart. There were 200 trees for each species in each windbreak.

Paddock 2. Windbreaks were planted with three different wind protection treatments (Figure 1). The first windbreak in the paddock was not protected throughout the experiment. The second windbreak in the paddock was protected for five months by maize which was then harvested while an existing perimeter mound gave protection to the boundary windbreak for the full 12 months of the trial.

Maize seeds were sown on a 800 m long, 220 m wide rectangular site within Paddock 2 on 15 December 1991. Windbreaks on Paddock 2 were planted on 9 January 1992. The north side windbreak was protected by maize while the south side windbreak was unprotected (Figure 1). The distance between maize and the tree row was 2 m.

Both of the windbreaks adjacent to the maize were made up of three rows of trees, one row of *C. salignus* and *M. armillaris* on the windward side, one row of *E. tessellaris* and *E. torelliana* in the middle, and one row of *E. microcorys* on the leeward side (Figure 1). As these species have different heights when mature (Boland *et al.* 1984), this particular arrangement of species adopted here would form a windbreak with a vertically uniform porosity (Marshall 1967). The boundary windbreak, consisting of four rows, was protected by the perimeter mound. Its first three rows from the windward side had the same structure as the other two windbreaks while the fourth row, on the leeward side, was made of *E. microcorys* (Figure 1). The distance between the windward and middle rows was 2 m and that between the middle and leeward rows was 4 m. Within each windbreak, *C. salignus* and *M. armillaris* were planted in sequence with five trees each with a 2 m intra-row spacing, *E. tessellaris* and *E. torelliana* were planted in sequence with 20 trees each spaced at 4 m apart while *E. microcorys* was planted also 4 m apart. For the boundary windbreak, the distance between the perimeter mound and the first row was 2 m.

On the remaining areas of both paddocks (Figure 1), peanuts were planted one week after tree planting and harvested in June 1992. Peanut plants were about 30 cm tall when harvested. The peanut areas were fallowed for the rest period of this study.

Measurements

Paddock 1. An automatic weather station was located about 2.5 km from the study site. Because the study site and weather station were relatively close with no undulating topography between them, wind direction and speed measured by the station were considered similar to those on the study site. Wind direction and speed were recorded at intervals of two hours throughout the experiment.

Maize height was observed and recorded during the experiment. Tree height (length of stem), angle to ground and tree crown size were measured at age five months when the maize crop was being harvested. In both the protected and unprotected windbreaks, these measurements were taken from 40 randomly selected trees of each species. These randomized trees were chosen in the section starting at 50 m from the eastern boundary and ending at 50 m from the western boundary to exclude any possible edge effects. For each selected tree, two perpendicular cross diameters of tree crown were measured with the first one randomly chosen, and the product of these values was used as crown size (m^2). Tree angle to ground was measured using a protractor at 30 cm from the base. An angle of zero degree indicates a completely prostrate tree while an angle of 90 degrees indicates a straight standing tree.

Paddock 2. Five months after the trees were planted, wind speed was measured at two positions from the perimeter mound on the study site at a height of 1.5 m above the ground. A data logger was used to collect these measurements at 2 - hour intervals throughout the remaining period of the experiment. The two positions were at 3 m and 50 m from and perpendicular to the mound. Wind direction was measured at the 50 m position every two hours. The 50 m was considered far enough from the perimeter mound for this position to be fully exposed to the wind. The wind speed measured at this position was used as a control (non-sheltered).

Tree height, angle to ground and tree crown size were measured at age 12 months. In each of the protected and unprotected windbreaks, these measurements were taken from 30 randomly selected trees of each species using the same methods described in Paddock 1.

Data analysis

The data were subjected to unpaired *t*- tests and regression analysis (Zar 1984). For each species, tree angle to ground, height and crown size of the unprotected trees were also expressed as a percentage of that of the protected trees, named relative angle, height and crown size respectively. These relative values were used to assess quantitatively the protection effect of both the perimeter mound and maize on young tree growth.

Results

Paddock 1

Wind xspeed and direction. The wind came from the southeast on 116 of the 150 days of the experiment. Of these 116 days, there were 58 days on which the maximum wind speed was greater than 20 kilometres per hour, 49 days 10 - 20 kph, and nine days less than 10 kph.

Maize height

The maize was 0.60 m tall when the trees were planted and grew to 1.4 m within two weeks. The maize attained its maximum height of 2.2 m four weeks after tree planting.

Tree growth

At five months, the mean height of the unprotected trees of each species was significantly ($p<0.01$) less than that of the protected trees (Table 1). *E. microcorys* trees were taller than *C. salignus* and *M. armillaris* trees in both the protected and unprotected situations.

The relative heights in Table 1 show that compared with the protected trees, the plant height of the unprotected trees was reduced by 14% for *C. salignus*, 15% for *E. microcorys* and 22% for *M. armillaris.*

For each species, the mean angle to ground of the protected trees was greater than 80^0 while that of the unprotected trees was less than 45^0 (Table 1). The difference between the protected and unprotected trees was significant ($p < 0.005$). All trees leaned towards the northwest. *Eucalyptus microcorys* had smaller relative angles to ground compared with *Callistemon salignus* and *Melaleuca armillaris* (Table 1).

The mean crown size of the protected trees of each species was significantly ($p \leq 0.001$) greater than that of the unprotected trees (Table 1). For both the protected and unprotected trees, *E. microcorys* had a greater crown than *C. salignus* and *M. armillaris.* No clear signs of physical damage to tree leaves were found.

For each species, the angle to ground of the unprotected trees decreased as plant height increased (Table 2). These negative correlations were all statistically significant. There were no clear trends for the protected trees ($r^2 \leq 0.24$, $p < 0.25$). No significant correlation was found between crown size and angle to ground for any of the species in either protected or unprotected mode.

Paddock 2

Wind speed and direction. Eighty-one per cent of the recorded wind directions at the experiment site came from the southeast, and wind speed was mostly between

Table 1. Tree angle, height and crown size of each species on Paddock 1 with (±) standard errors and the value of the unprotected trees expressed as a percentage of the protected trees. P=protected and U=unprotected

Species	Height (m)			Tree angle to ground			Tree crown size (m x m)		
	P	U	U/P%	P	U	U/P%	P	U	U/P%
Callistemon salignus	0.9 ± 0.02	0.77 ± 0.01	85.5	83.5 ± 1.7	42.6 ± 1.9	51.0	0.059 ± 0.006	0.037 ± 0.003	62.7
Eucalyptus microcorys	1.36 ± 0.02	1.15 ± 0.03	84.5	78.1 ± 2.2	33.0 ± 2.1	42.3	0.305 ± 0.021	0.211 ± 0.011	69.2
Melaleuca armillaris	0.96 ± 0.03	0.75 ± 0.02	78.1	85.3 ± 1.6	44.9 ± 2.1	52.6	0.064 ± 0.005	0.036 ± 0.002	56.2

10 kph and 30 kph. Wind speed at 3 m from the perimeter mound was much less than that at the open area throughout the day (Figure 2). At most times of the day wind speed in the sheltered area was reduced by about 85% compared with the open area.

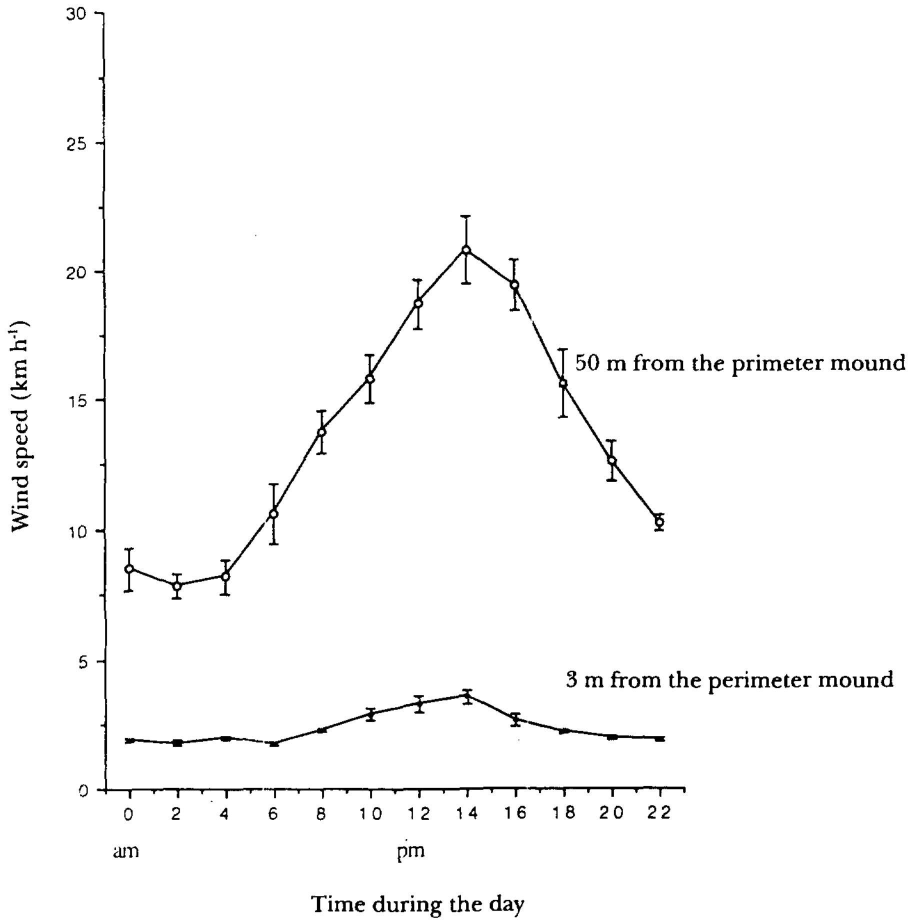

Figure 2. Mean wind speed measured throughout the experimental period at positions 3 m and 50 m from the perimeter mound in Paddock 2 with standard error bars for each measurement time

Tree growth

For each species, mean height of the trees protected for 12 months was significantly ($p < 0.005$) greater than that of the trees protected for only the first five months which in turn was significantly greater ($p \leq 0.025$) than the unprotected trees (Table 3). *E. microcorys* and *E. torelliana* were taller than the other three species in the three wind protection treatments.

Table 2. Correlation model of angle to ground of unprotected trees with plant height for each species. y = a + bx; y = angle to ground (°); x=plant height (m)

Species	a	b	r^2	*F*-test	p-value
Paddock 1					
Callistemon salignus	122.50	-92.47	0.729	75.4	≤0.0001
Eucalyptus microcorys	144.61	-76.44	0.689	61.9	≤0.0001
Melaleuca armillaris	112.64	-84.67	0.626	46.8	≤0.0001
Paddock 2					
Callistemon salignus	110.14	-46.36	0.772	94.8	≤0.0001
Eucalyptus microcorys	103.25	-20.95	0.836	142.6	≤0.0001
E. tessellaris	22.10	10.00	0.106	3.3	0.05<p≤0.1
E. torelliana	107.84	-31.99	0.607	43.2	≤0.0001
Melaleuca armillaris	102.09	-40.60	0.599	41.9	≤0.0001

The relative heights of the species are shown in Table 3. Of all the species, *E. microcorys* and *C. salignus* had the smallest relative tree heights.

For each species, trees protected by the perimeter mound for 12 months had the greatest angle to ground while the unprotected trees had the least angle (Table 3). The difference between any two of the three wind protection treatments was significant ($p < 0.005$). All trees leaned towards the northwest.

Table 3 shows that *Eucalyptus microcorys* had the lowest relative angles and *E. torelliana* had the highest values. For *E. microcorys*, the unprotected trees were leaned 67% more than trees protected for 12 months and 53% more than trees protected for five months.

For each species, mean crown size was greatest for trees protected for 12 months, moderate for trees protected for the first 5 months and smallest for the unprotected trees (Table 3). The difference between any two of the three wind protection treatments was significant ($p<0.005$). *E. torelliana* had a larger crown than the other species. For *E. microcorys* and *E. torelliana*, some wind burn signs were observed on the leaves of both the unprotected trees and the trees protected by maize for five months. No clear signs of physical damage to tree leaves were found for *C. salignus*, *E. tessellaris* and *M. armillaris*. Among the species, *M. armillaris* had the lowest relative crown size (Table 3).

For each species, there was a significant correlation between angle to ground of the unprotected trees and plant height (Table 2). There were no significant correlations between crown size and angle to ground.

Discussion

The fact that the prevailing wind came from the southeast during the period of the study and trees markedly leaned towards the northwest clearly showed that tree inclination was caused by wind. This is also strongly supported by the result that wind speed at the sheltered area in Paddock 2 was 85% less than in the open. The reason why the protected trees were also inclined may be because for the maize

Table 3. Tree angle, height and crown size of each species on Paddock 2 with (±) standard errors, and the value of the unprotected trees expressed as a percentage of the protected trees. P-5m=protected by maize for five months, P-12m=protected by soil mound for 12 months, U=unprotected

Species	Height (m)			Tree angle to ground			Tree crown size (m × m)		
	P-5m	P-12m	U	P-5m	P-12m	U	P-5m	P-12m	U
Callistemon salignus	1.6 ± 0.06	1.8 ± 0.09	1.2 ± 0.06	61.8 ± 2.3	86.0 ± 1.7	32.6 ± 2.1	1.1 ± 0.07	1.4 ± 0.07	0.95 ± 0.08
U/P-5m%			72.5			52.8			83.3
U/P-12m%			65.5			37.9			69.3
Eucalyptus microcorys	2.9 ± 0.15	3.4 ± 0.13	2.1 ± 0.13	57.4 ± 2.3	82 ± 1.8	27.2 ± 1.9	3.3 ± 0.45	4.1 ± 0.85	2.7 ± 0.45
U/P-5m%			74.7			47.4			80.6
U/P-12m%			62.1			33.3			64.9
E. tessellaris	1.9 ± 0.09	2.0 ± 0.11	1.6 ± 0.08	72.1 ± 1.7	88 ± 0.78	46 ± 1.90	1.4 ± 0.06	1.8 ± 0.09	1.0 ± 0.06
U/P-5m%			83.2			63.5			74.3
U/P-12m%			77.5			52.3			57.1
E. torelliana	2.8 ± 0.11	3.2 ± 0.12	2.4 ± 0.12	75 ± 2.40	89 ± 0.53	49 ± 2.90	5.2 ± 0.60	7.0 ± 0.60	4.2 ± 0.40
U/P-5m%			84.6			65.1			80.8
U/P-12m%			73.5			54.7			60.0
Melaleuca armillaris	1.7 ± 0.08	1.9 ± 0.09	1.3 ± 0.06	68 ± 2.30	85 ± 0.58	36 ± 1.80	1.3 ± 0.04	1.5 ± 0.05	0.8 ± 0.05
U/P-5m%			76.5			52.6			63.8
U/P-12m%			70.3			42.1			55.3

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protection, trees were not effectively protected in the first two weeks after planting as maize was short at that time. Also for the perimeter mound protection, wind speed was not reduced to zero and trees were still subjected to some winds. However, the effects caused by these winds on tree growth were minimal. Wind affected young tree growth in this study as evidenced by the differences in plant height and tree crown growth between the protected and unprotected trees.

Since wind caused a reduction in plant height growth, it appears that windbreak establishment on unsheltered areas is likely to be slowed down by wind effects. Because of wind induced lean, the quality of windbreaks may be reduced if they are subjected to strong wind during establishment. It is of interest to note that for each species, the relative angles were much smaller than the relative heights and crown sizes. This suggests that wind may cause a greater negative impact on the quality of the windbreak than on the quantitative growth of trees, at least for the species studied.

Both the perimeter mound and maize provided important protection to young trees from wind effects. The faster growth of the sheltered trees in this study may be attributed to a more favourable microclimate provided by shelterbelts as suggested by Caborn (1957), and Applegate and Bragg (1989). The protection of perimeter mound and maize could probably have been improved if they were oriented on a NE/SW direction as the optimal shelterbelt orientation is 90^0 to prevailing winds (Marshall 1967).

The fact that trees protected for 12 months were less affected by wind than trees protected for only the first 5 months in Paddock 2 suggests that a long protection period for young trees, say 12 months in tropical conditions, is important. Although a perimeter mound with grasses can provide such protection, it is not practical to construct in most cases, particularly when windbreaks are to be established within paddocks. Planting some perennial tall grasses as windbreaks for treebelt establishment may be a more effective and practical technique. Alternatively, trees on the windward side may be planted in the first year and those in the leeward planted in the subsequent year. Thus the trees planted later may be protected by trees planted in the previous year.

Within a single species, taller trees are likely to lean more than shorter trees when subjected to wind impact. This contradicts the wishes of farmers who normally hope trees will grow fast in their early stages and for a quick formation of windbreaks, thereby reducing labour for maintenance, such as weed control. One solution is to shelter trees when young.

E. microcorys appeared to be affected more by wind than the other species indicating that it may be more susceptible to wind damage than the other species studied. This suggests that resistance to wind damage should be an important criterion for species selection when forming windbreaks in windy areas.

Conclusion

Because it is frequently windy on the farm lands which require shelterbelts, the establishment of windbreaks on such areas will be affected by wind. Using tall annual crops to protect windbreaks during establishment appears to be a useful technique, while using perennial tall grasses may be more effective as they can provide a longer period of protection and are easily established, at least in tropical conditions. These established windbreaks will in turn provide protection for crops from wind damage. This reflects a mutually beneficial effect between windbreaks and crop growth in agroforestry systems.

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