Windbreak Benefit to Potato Yield in Tropical North Australia

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A study was conducted on the Atherton Tablelands of tropical north Australia to quantify the benefit of a 18-month-old windbreak to the production of potato (Solanum tuberosum *L.). In the leeward side, wind velocity and potato yield were measured at various distances from the windbreak. Wind direction on the study site was also monitored. Non-linear modeling was used to describe the relationship between potato yield and distance from the windbreak. The definite integral was applied to the developed model to calculate the net increase percentage of potato yield. Wind velocity was greatly reduced by the windbreak, and potato yield was increased by 6%. It appears that fitting non-linear models is a useful method to determine an accurate net increase of crops from windbreaks.* Tree Planters' Notes 47(3):110-115; 1996.

As wind can cause losses to crop yields (Bates 1917; Caborn 1957; Frank and others 1974; Grace 1988), windbreaks have been considered as an important component in agriculture management systems (Marshall 1967; Sturrock 1988). Kort (1988) noted that windbreaks increase crop yield and the degree of this positive effect varies with climatic condition, soil type, crop variety, and the management practices. Because of the variety of these variables, studies on windbreak benefits to specific crops grown under different conditions are necessary (Sturrock 1988).

Potato growing is a major agricultural activity on the Atherton Tablelands of north-eastern Australia, where frequently strong winds can reduce the yield of this high--value crop (Sun and Dickinson 1994). Accurate information on the windbreak benefits to this crop is urgently needed to provide guide-lines for windbreak design, establishment, and management. Many studies have shown that crop yield was increased by windbreaks (Puri and others 1992; Stoeckeler 1962; Sturrock 1981). Kort (1988) reported an approximate 3.5% net increase in spring wheat yield. Sturrock (1981) reported an average increase of 35% in wheat yield. Puri and others (1992) found an up-to-10% increase in cotton yield. In these studies, crop yields were generally measured at various positions away from the windbreak. As these data are non-linear, the accuracy of the net gain of windbreaks on crops calculated from them are questionable. In order to quantify net gain from windbreaks in relation to crop yield, there is a need to develop a more accurate method.

Sun and Dickinson (1994) studied the effects of mature windbreaks on potato yield. However, it appears that young windbreaks have different patterns in affecting wind velocity and crop growth from mature windbreaks, suggesting that the age of windbreaks is important. This paper reports a study carried out from June to October 1993 to quantify the benefit of a young windbreak to the production of potato *(Solanum* tuberosum L.) on tropical farm land of northeastern Australia.

Methods

The study site was on a paddock, 5 km (3.1 m) from Atherton, in northeastern Australia— lat. 17/10' S, long. 145/28' E, alt. 710 m (2,329 ft). The site is flat, with a red euchrozem soil. The paddock has been used to grow crops of maize, peanuts, and potatoes in rotation for at least 60 years. The prevailing winds in this area are southeasterly. The average daily maximum temperature is about 32 /C (90 /F) for the hottest months (December and January) and the mean daily minimum temperature for the coolest month (July) is about 10 /C (50 /F).

The site is sheltered by three 18-month-old windbreaks that were planted in the direction as shown in figure 1. The windbreaks were 4.5 m (14.8 ft) tall. As the study was carried out in the dry season, the windbreak grew little during the period of the study. Seven native species with different heights when mature were used to form the windbreaks:

- 1 tall species— *Eucalyptus microcorys* F. Muell. (up to 40 m tall)
- 2 medium species— *E. tessellaris* F. Muell. and *E. torelliana F.* Muell. (up to 30 m tall)
- 4 short species— *Callistemon salignus* (Smith) DC., *C. viminallis* Smith, *Melaleuca armillaris* Smith, and M. linariifoli Smith (up to 6 m tall)

The southern boundary windbreak (figure 1) was used for the study. It was made up of 4 rows: 1 row of short trees on the windward side, 1 row of medium trees in the middle, and 2 rows of tall trees on the

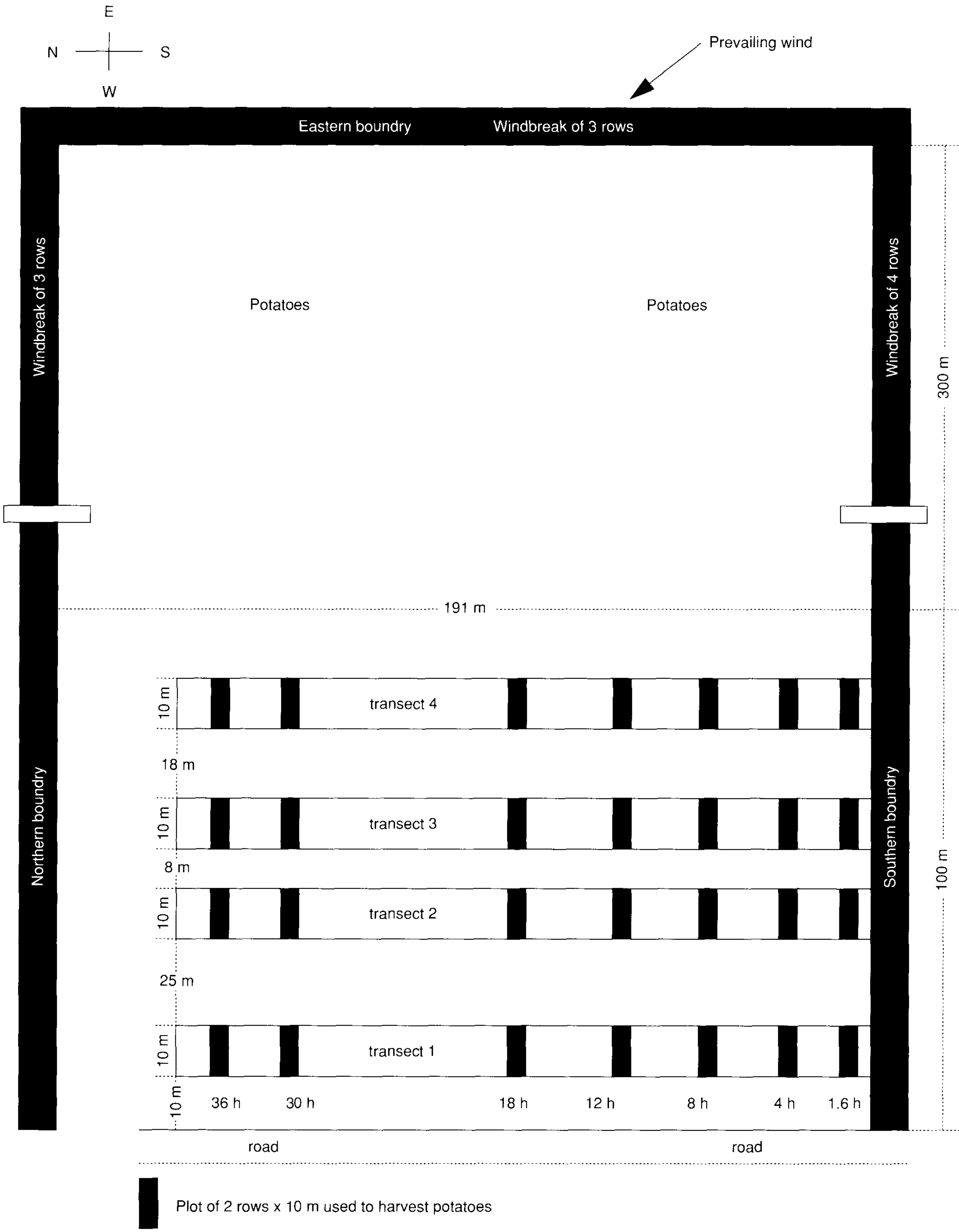

Figure 1— *The layout of windbreaks and the transects for potato sampling adopted on the study site.*

leeward side. The short-tree row and the middle row were 2 m (6.6 ft) apart, and the middle row and the tall-tree rows were 4 m (13.1 ft) apart. The intra-row spacing of trees was 2 m on the short-tree row and 4 m on both the middle and tall-tree rows. The 2 medium species were planted in a sequence of 20 trees/species whereas the 4 short species were planted in a sequence of 5 trees/species.

Windbreak porosity and wind measurements. Windbreak porosity was measured using the SCISCAN software developed by the Commonwealth Scientific and Industrial Research Organization (CSIRO) of Australia. The software was based on the principles of image digitization (Yanuka and Elrick 1985). A photograph of the windbreak was taken and was then scanned into a PC computer using a HS3000 scanner. As the windbreaks were orientated 45/ to the prevailing wind, the photograph was taken at an angle of 45/ towards the prevailing wind direction. The porosity was then calculated using the SCISCAN. The porosity of the windbreak was 51 %. There were some small gaps in the top section of the windbreaks.

During the period of potato plant growth, wind velocity was measured at 7 positions along a transect perpendicular to the south boundary windbreak. In order to avoid potential small animal damage to the wind velocity sensors, wind velocity was measured at a height of 2 m (6.6 ft) above the ground, although a height of 0.5 m (20 in) above the ground would be more appropriate as mature potato plants were only slightly shorter than 0.5 m. A GBL-8+8-128 data logger was used to collect these measurements at 30-minute intervals throughout the experiment. The 7 positions were at 4.5, 13.5, 27.0, 54.0, 81.0, 108.0, and 144.0 m (14.8, 44.3, 88.6, 177.2, 265.7, 354.3, and 472.4 ft) from the south boundary windbreak, which were 1, 3, 6, 12, 18, 24, and 32 times the windbreak's height (*h*), respectively. Wind direction was measured at 18 *h* every 30 minutes. It would be desirable to monitor wind velocity on the windward side while measuring wind velocity at those 7 positions mentioned above. This was, however, not practical as only 7 channels in the logger were available to measure wind velocity and the cable lengths between the 7 wind-velocity sensors were limited. Because 32 *h* was far enough from the windbreak, this position was most likely to be fully exposed to the wind. For all the southeasterly winds, the wind velocity measured at this position was used as a control in the present study.

Potato yield measurements. Potato seeds of the certified variety called 'Atlantic' were planted on a 100 × 191 m (328.1 × 626.6 ft) section on the leeward side of the southern boundary windbreak (figure 1) on June 25, 1992. "Q5", a commercially available fertilizer (5% N, 6.8% P, 4% K), was applied at planting at a rate of 2.2 t/ha (0.9 t/ac). Urea (46% N) was applied 2 weeks after planting through irrigation at a rate of 0.25t/ha (0.1 t/ac). Four transects (replicates) with 10 m in width by 162 m (32.8 × 531.5 ft) in length, were set up perpendicular to the windbreak. To avoid the effect from the eastern boundary windbreak, the 4 transects were randomly set within the potato section >300 m (328.1 ft) from the eastern boundary windbreak (figure 1). Along each transect, 7 plots of 2 rows, 1 m (3.28 ft) in width and 10 m (32.8 ft) in length were placed at 1.6, 4, 8, 12, 18, 30, and 36 *h* from the southern boundary windbreak. Potatoes were harvested from each plot and yield measured (t/ha) on 8 October 1993. The harvested potatoes were graded into 2 groups according to their sizes:

grade A— diameter >8 cm (3.2 in)
grade B— diameter<8 cm (3.2 in)

Grade B has a lower commercial value than grade A. Potatoes grown at <1.6 *h* were not harvested because the landholder had grown section different varieties of potatoes between the windbreak and 1.6 *h*.

Data analyses. The difference in potato yield between the 7 distances from the windbreak was tested using analysis of variance. The differences between any 2 distances were further tested using LSD (least significant difference). Non-linear modeling using GENSTAT (Genstat 5 Committee 1988) was used to describe the relationship between potato yield and distance from the windbreak. The curve of best fit, based on the value of correlation coefficient, was selected from fitted linear, power and exponential functions.

Results

Wind parameters. Throughout the period of the experiment, 75% of the wind measured came from the southeast whereas 3.5% (the smallest proportion) came from the north and northeast (table 1). Overall, for the south easterly winds, the velocity increased with the increase in distance from the windbreak (table 2). The relative wind velocity shown in figure 2 indicates that wind velocity at 1, 3, and 6 *h* was 77, 68, and 24% less than that in the open area. Wind velocity became constant after 18 *h*.

Table 1—*Percentage of wind direction throughout the period of the experiment (wind direction was divided into 5 categories according to their potential effect on the potato section studied)*

N–NE 0–80°	NE–SE 81–110°	SE–S 111–180°	SW–W–SW 181–270°	SW–W–NW 271–359°
3.5%	6.6%	74.5%	7.3%	8.1%

Table 2—*Mean wind velocity with standard errors at various distances from shelterbelts (in multiples of height of shelterbelt* h)

Mean wind velocity (km/hr)						
1 × *h*	3 × *h*	6 × *h*	12 × *h*	18 × *h*	24 × *h*	32 × *h*
2.68±0.07	3.73±0.11	8.79±0.13	10.74±0.13	11.55±0.19	11.57±0.14	11.58±0.13

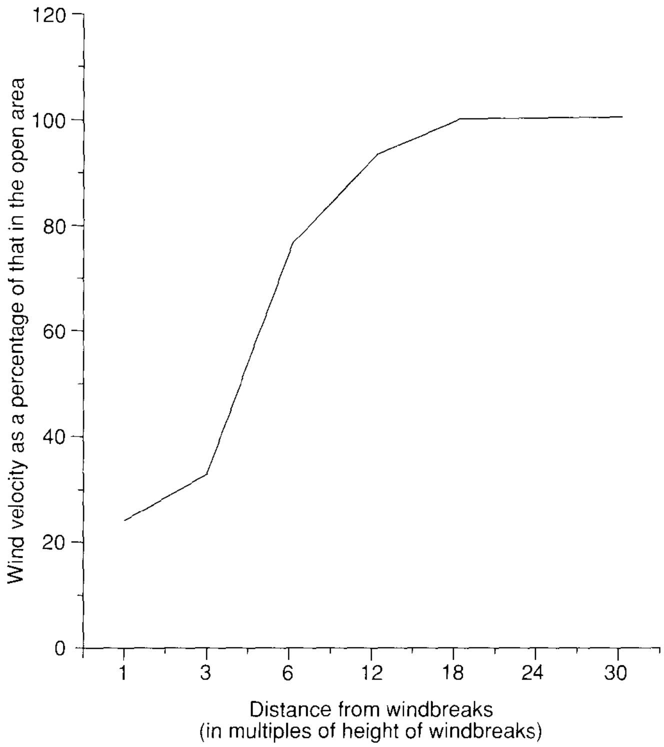

Figure 2— *Wind velocity expressed as a percentage of that in the open areas versus distance along the perpendicular line from the windbreak in the leeward side.*

Potato yield. With the increase in distance from the windbreak, the yield of grade B potatoes changed little (table 3). Potato production for total and grade A changed significantly with the distance from windbreak (table 3). They increased in the areas between 1.6 and 8 *h* and decreased in the areas between 8 and 18 *h* (table 3). Both grade A and total potato yield became relatively constant after 18 *h*. The mean yield at each of 18, 30, and 36 *h* was considered as the average of the open areas (unsheltered areas) which was 15.976 t/ha for total and 17.349 t/ha for grade A. Based on the further LSD test results (table 3), the 7 distances can be divided into 2 groups. The distances of 1.6, 4, and 8 *h* form the first group, while the others form the second group. Potato yield for both the grade A and total in the first group was significantly greater than that in the second group.

Table 3—*Potato yield with standard errors measured at various distances from shelterbelts with ANOVA results (df=21), LSD is calculated at* P=0.05

Distance from shelterbelts (*h*)	Potato yield (ton/ha) Grade A	Grade B	Total
1.6	18.793 (±0.370)	1.185 (±0.037)	19.978 (±0.354)
4	19.188 (±0.289)	1.365 (±0.015)	20.553 (±0.285)
8	19.370 (±0.293)	1.255 (±0.045)	20.625 (±0.296)
12	16.518 (±0.427)	1.308 (±0.075)	17.825 (±0.454)
18	15.838 (±0.405)	1.350 (±0.117)	17.188 (±0.514)
30	16.140 (±0.412)	1.345 (±0.128)	17.485 (±0.482)
36	15.950 (±0.380)	1.423 (±0.048)	17.373 (±0.424)
ANOVA			
F-value	21.74**	1.12	16.44**
LSD	1.014		1.134

A critical exponential model was developed to describe the relationship between the potato yield and the distance from the windbreak (represented by d in the model).

$$Yield_{grade\ A} = 15.831 + (-0.1 + 2.79 \times d) \times 0.7658^{d}$$
$(R^2=0.785)$

$$Yield_{total} = 17.191 + (-0.68 + 3.04 \times d) \times 0.7575^{d}$$
$(R^2=0.789)$

Figure 3 shows the fitted curves of both the total and grade A potato yield using the models given above. The total and grade A yield in the section of 1.6 to 18 *h* was above the average and was an increase (figure 3). Based on the models, the net increase % in potato yield resulting from the windbreak was calculated as below.

$$Increase_{grade\ A} = \int_{1.6}^{18} (f(d)_{grade\ A} - 15.976)\, dd$$

$$Increase_{total} = \int_{1.6}^{18} (f(d)_{total} - 17.349)\, dd$$

$$f(d)_{grade\ A} = Yield_{grade\ A};\quad f(d)_{total} = Yield_{total}$$

$$Net\ increase_{grade\ A} = increase/(18\text{-}1.6) = 0.9602\ (t\ /ha)$$

Net increase % of the average total yield in open

$$\text{area} = \frac{\text{Net increase}_{\text{total}}}{17.349} \times 100\% = 4.9\%$$

The net increase% of the average grade A yield is greater than that of the average total yield.

Discussion

It appears that the 18-month-old windbreak studied can effectively reduce wind velocity to 12 *h* in the lee of the windbreak. This effect is likely to be improved when the windbreak becomes older and more branches and leaves are developed. Some mature windbreaks were found to reduce wind velocity to 30 *h* in the leesides (Marshall 1967). The windbreak studied is also likely to be more effective if it was oriented on a NE/SW direction as the optimal windbreak orientation is 90% to prevailing winds (Sturrock 1988).

Because only a small proportion of winds came from the NW-NE, the northern boundary windbreak would have little effect on the sampled potato yield. This was evidenced by the fact that the potato yield was similar at 18, 30, and 36 *h* from the southern boundary windbreak, which were 24.4, 12.4, and 6.7 *h* from the northern boundary windbreak, respectively.

The windbreak studied had a positive effect on potato yield. It appears that the benefits of windbreaks may be greater to potato size than to overall quantity. Overall, the positive effect was much smaller than that found by Sun and Dickinson (1994), Sturrock (1981), and Puri and others (1992). Although this may be because crops vary in their response to windbreaks (Kort 1988), the main reason may be because the windbreak in the present study was young.

Lyles and others (1984) reported a reduction of winter wheat production to a distance of 2 *h* from windbreaks due to shading effects and competition between trees and crops. The fact that the potato yield at 1.6 *h* was greater than that in the open areas suggests that the windbreak studied did not cause a loss at least from 1.6 *h.* However, as the wind velocity increase dramatically between 1 *h* and 12 *h* but the yield at 1.6 *h* was less than that measured at 4 and 8 *h,* there may be a competition and shading effect from the windbreak on the potato plants at 1.6 *h.* This competition effect was likely to be smaller than the positive effect from windbreak and therefore did not cause a loss.

It appears that when soil conditions and management practices throughout a growing season are relatively uniform, fitting non-linear models and applying the definite integral of the models is a useful method in determining a net increase of crops from windbreaks. However, the usefulness of this method depends greatly on whether an accurate assessment of the average crop yield on the open areas is achieved. In the present study, the yield became relatively constant after 18 *h*. The evaluated average yield in the open areas was, therefore, reasonably accurate.

It appears that young windbreaks do have different patterns in affecting wind velocity and crop growth from mature windbreaks. Studies are needed to determine the age at which a windbreak starts to have a full effectiveness. This information is important when planting windbreaks is considered as a necessary component in a farm management system.

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