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Assessing the value of trees in sustainable grazing systems

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Abstract

The retention of trees in strips provides an option for managing non-remnant woody vegetation in native and sown pastures in northern Australia. However, the impact of tree strips on pasture production has not been previously researched in detail in southern Queensland. The influence of existing tree strips on pasture production in southern Queensland was measured at three grazing properties during 2004 and 2005. Soil and pasture attributes were sampled along transects 80 to 300 metres in length positioned perpendicular to tree strips. The tree strips ranged from 15 to 75 metres wide and were 120 to 500 metres apart. The effects of tree strips along the pasture transect were quantified in terms of pasture microclimate (e.g. temperature, humidity and, at one location, wind), pasture growth in grazed and exclosed situations, soil water, soil nutrients and condition, and nutrient availability. An experimental approach using exclosed pasture transects provided a useful 'bioassay' potentially integrating beneficial and competitive effects of tree strips on pasture growth as well as other factors (e.g. soil variability).

Averaged across two locations and two years, the competitive effects of the tree strip were compensated to some extent by enhanced pasture growth at distances of 1-6 x tree height from the tree strip edge. However, the observed effects on pasture growth along the transect were likely to be due to different causes: pasture microclimate at one site, soil texture and microtopography at a second site and pasture establishment history at a third site. Thus, the trial highlighted the difficulty of attributing effects in real-world situations, given the number of possible causes including the tree strip effects on pasture microclimate and nutrient availability, soil surface disturbance, and systematic variation on soil and water redistribution due to soil micro-topography and felled timber. Despite these many sources of variation, general effects were derived from the field data consistent with other studies on tree strips and wind breaks across Australia. To extrapolate the project results to other locations, tree strip configurations and climates, a new version of the soil water-pasture growth simulation model GRASP was developed allowing simulation of tree and pasture effects and processes for various distances along a pasture transect perpendicular from the tree strip.

Executive Summary

There are about 60 M ha of grazed woodlands in Queensland and, historically, tree clearing was an important management tool to improve pasture production. With the cessation of remnant tree clearing following the enactment of State legislation, the emphasis has shifted to the development of woody regrowth management plans. The retention of trees in strips provides an option for managing non-remnant woody vegetation for a range of purposes, including for aesthetics, conservation of biodiversity and landscape hydrology. Further, observations by some landholders in southern Queensland suggested that in some situations, tree strips may actually enhance pasture productivity. However, there were little data on the impact of tree strips on pasture production in this environment.

The objectives of the project were to:

1) define in quantitative terms the beneficial and competitive effects of trees on surrounding grazing systems in southern Queensland;
2) develop the modelling capacity (within the GRASP growth model) for evaluation of the impacts of different tree and regrowth configurations and management on the grazing systems in terms of productivity and sustainability; and
3) develop and publish tree and grass management guidelines and associated extension and education materials for beef producers and distribute the publications.

The influence of existing tree strips on pasture production was measured intensively on three grazing properties (Duke's Plain near Theodore, Mt Lonsdale near Mungallala, and Moombah near St George) in southern Queensland during 2004 and 2005. Soil and pasture attributes were sampled along transects 80-300 metres in length positioned perpendicular to tree strips. The tree strips ranged from 15-75 metres wide and were 120-500 metres apart. The tree strips varied in terms of woody and pasture vegetation, dimensions (width and length), tree height and basal area, and orientation. Measurements included pasture microclimate, pasture growth and botanical composition, pasture nitrogen and phosphorus concentrations, soil nutrient status and soil microbial activity, and soil water.

Pasture growth was measured for the 2003-04 and 2004-05 growing seasons at two locations (Duke's Plain, Mt Lonsdale), and only for the 2004-05 season at the third location (Moombah). Pasture growth along exclosed transects was compared to 'open pasture' growth defined as the zone from 4.5 to 8 x tree height from the edge of the tree strip. For both years of measurement at Duke's Plain and Mt Lonsdale, there was an increase in pasture growth in the zone of approximately 2 x tree height (20-30% above 'open pasture' growth). Average pasture growth within the tree strip at Duke's Plain and Mt Lonsdale was 45% of 'open pasture' growth (range 32-67% across four combinations of years and locations). On average, the estimated beneficial effect (compared to open pasture growth) of tree strips spanned approximately 1-6 x tree height along the pasture transect. Pasture growth responses at Moombah were also recorded, but were much closer to the tree strips and appeared to be confounded by the pattern of ash beds resulting from recent burning of cleared timber associated with pasture establishment at this site.

The beneficial effects of tree strips on pasture growth at Duke's Plain are likely to be a result of modification of the adjacent pasture microclimate. Previous studies have shown that, when winds are perpendicular (or at a small angle) to tree strips, there are zones of lower wind speed and higher daytime temperature adjacent to the strips.. Daily wind run was measured intermittently at five different positions at one tree strip at Duke's Plain. The measurement of wind was difficult in terms of maintaining instruments in the field. The data indicated lower wind speeds on the generally downwind (north-west) side of the tree strip demonstrating the potential for tree strips to modify adjacent pasture microclimate.

Wind direction was not measured at the field sites. Data from relevant meteorological stations were evaluated in terms of frequency of wind from directions perpendicular, parallel and at 45 degrees to the tree strip. There was considerable variability in direction at diurnal, seasonal and yearly timescales. Nevertheless, in general terms, parallel wind directions were less frequent in the summer growing season for Moombah and Duke's Plain, whilst more frequent at Mt Lonsdale. Thus, larger effects on pasture microclimate would be expected at Moombah and Duke's Plain. Maximum daytime temperatures measured at Moombah and Duke's Plain indicated average increases of 0.2 to 2.0^{o}C for zones up to 2 x tree height, while there were only small differences in maximum temperature along the transect at Mt Lonsdale. Thus, the microclimate effects at the three sites were broadly consistent with aspect in terms of shade and frequencies of wind directions (relative to orientation of tree strips) for the years of the field study.

Modelling of tree-pasture effects

A simple algebraic model combining beneficial and competitive components was developed in this study from data at Duke's Plain and was used to integrate the effect of tree strips on whole transect pasture production. Both the empirical model, and interpolated SDM measurements along the pasture transect, showed that the competitive effects of the tree strip were compensated to some extent by enhanced pasture growth at distances 1-6 x tree height from the tree strip edge. The degree of compensation depends on tree strip width and distance between strips. In one example, based on Duke's Plain, 90-95% compensation in pasture growth occurred where the ratio of the area of tree strip to pasture was 1:4. The specific causes of enhanced pasture growth are likely to vary from location to location and between strips at a particular location limiting the application of the specific transect results.

Although there were similar relative effects of tree strips on pasture growth at Duke's Plain and Mt Lonsdale, there were large differences in measured pasture microclimate effects as described above. It is likely that the apparent effect of the tree strips on pasture production at Mt Lonsdale included the contributing effects of soil type changes, soil micro topography, timber debris, and runoff/run-on redistribution. In terms of quantifying these and pasture microclimate effects, more detailed work is required to reconstruct daily pasture microclimate data, and especially deriving wind and evaporative demand effects from the temperature differences along the pasture transect.

A component of the project was the modification of the soil water-pasture growth simulation model GRASP which is used extensively in northern Australia to represent and extrapolate the results measured in field projects.

A transect model was developed to simulate the change in important climate, soil and pasture parameters along a pasture transect perpendicular to a tree strip. The competitive effects of trees in terms of water and nitrogen uptake were represented using relationships from the algebraic model described above. The beneficial effects of tree strips on pasture transpiration use efficiency, radiation use efficiency and nitrogen use efficiency were similarly estimated. The resulting model reasonably represented the effect of tree strips on pasture production at Duke's Plain. There was insufficient data to test the model at the other sites.
This project was an initial study on the effect of tree strips in southern Queensland. Whilst highlighting the competitive and beneficial effects of tree strips on pasture growth, the project also demonstrated the difficulty of measuring the complex biophysical effects of tree strips and distinguishing these from the variation caused by any soil disturbance and by natural variation in soils and microclimate across the landscape. It is recommended that further study on tree strips of different orientation, location and year-types is warranted to build up a larger database than just the five year x location combinations documented in this report.

This study demonstrated that a relatively simple bioassay technique (exclosed transect to measure pasture growth) could provide an effective approach for data collection across a wide range of tree strip situations allowing quantification of the effect of orientation, configurations, variation in soil disturbance, pasture and clearing management, and soil type. The modelling study suggested that more intensive measurements including pasture microclimate and pasture physiological measurements on a few well chosen individual tree strips would allow the further development of a more general model which could be used in paddock and landscape design. However, the difficulty of maintaining and monitoring equipment, as found in this project, indicates that greater resources (people, travel) need to be committed for the field project to be successful.

The project documented in detail examples which showed that the expected competitive effect of tree strips was offset to some extent by zones of enhanced pasture growth (1-6 x tree height distant from the tree strip). However, in only one example (Duke's Plain) could these effects be attributed mainly to pasture microclimate. At other sites, variation in soil type, microtopography and pasture establishment history were likely to have larger effects. The results of the project form an initial basis for evaluating the impact of retaining trees in the landscape in southern Queensland for both individual graziers and the wider community.

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1 Background

1.1 An overview of the role of trees in sustainable grazing systems.

The design of more sustainable grazing systems requires an understanding of the effects of trees on the landscape, both competitive and beneficial. Ecological interactions may vary with stand age and health, tree density, distribution pattern, and climatic fluctuations. Generally, past research has focused on landscape scale off-site ecological impacts of tree removal such as loss of habitat for native biodiversity (Saunders *et al*. 1991; Barrett *et al*. 1994; McAlpine, *et al*. 2002); salinity risk (Williams *et al*. 1997), or the paddock level costs of retaining vegetation to farm profitability. Less attention has been paid to the effects of trees on surrounding production systems and the ecosystem services that may be provided (i.e. microclimate, nutrient cycling, landscape water processes).

At the paddock level, the focus has previously been on removing trees to increase pasture production, with the significant increases in pasture growth occurring due to tree clearing well documented for many woodlands in Queensland (Beale 1973, Burrows 1993, Gillard 1979, Gardner *et al*. 1990, Jackson and Ash 1998, McIvor and Gardner 1995, Scanlan 1991, Scanlan and Burrows 1990, Walker *et al*. 1972, Walker *et al*. 1986). However, there are also studies that question the long-term sustainability of the resource base from the removal of the native woody vegetation (e.g. Williams *et al.* 1997).

Further, there is a growing belief within the grazing community that tree retention can be designed to maximise environmental benefits while allowing an economically viable level of production. Production benefits are expected through: minimising microclimatic extremes, providing shade and shelter for stock; improvements in pasture nutritional quality; mitigation of potential landscape imbalances in the hydrological, energy flow and nutrient cycles that cause on and off-site environmental degradation (such as dryland salinity and reduced water quality); the value of retaining timber for harvesting, and possibly carbon sequestration.

Indeed there is evidence from southern states that windbreaks can be beneficial to crop and pasture production. Shelter belts, while reducing crop yields adjacent to the tree line, can lead to increases in production to a distance of up to 25 tree heights, due to moisture savings, higher CO_2, higher soil temperature and less wind damage (Bird 1984). In temperate climates, pasture and crop yields were increased by up to 30% in a downwind zone extending about ten times windbreak height (Breckwoldt 1986, Bird 1984). In areas prone to frosting, tree clearing has been shown to lead to minimum temperatures 2-4^{0}C colder, and herbage remained green when all herbage in cleared areas had been frosted (McIvor 1998). Reid *et al*. (in preparation) found substantial production gains from young (5-7 year old) windbreaks in recently fertilised native pastures (compared to treeless fertilised pastures) with sheep stocking rates increased by 42% and wool production increasing by 32%.

Despite the introduction of heat tolerant cattle, most landholders see tree retention desirable at least for stock shade (Daly 1984) and shelter. Shade may enable cattle to graze longer during the day, may extend the usage to areas well away from watering points, as well as improve fertility and survival rates.

To begin to address these complex issues the following report represents an initial evaluation of the role of the strips of retained woody vegetation in southern Queensland.

1.2 Review of past research specific to Queensland and Northern Australia.

Assessments in the late 1970s indicated that in Queensland, approximately 87% of the 173 M ha of the State was covered by native or naturalised pastures (Weston *et al*. 1981). There are about 60 M ha of grazed woodland communities (Burrows *et al.* 1988). There are also about 16 M ha of national parks, State forests and timber reserves which support moderate to dense woodland or forest cover. The original cover of forests, woodlands and shrublands for the State is estimated at about 100 M ha (Burrows *et al*. 1988). Apart from mulga, the woody dominants in these communities are largely not important as a forage resource from a domestic livestock production point of view.

The production benefits to graziers of responsible and sensible management of woody plant populations are quite substantial over most of Queensland, especially in southern and central parts of the State (Burrows *et al.* 1990). There are major financial benefits to individual landholders, especially in the short-term, arising from applying woodland management and woody weed control (Harrington *et al.* 1984, Rolfe 1999, 2002). This has resulted in these practices being almost universally implemented throughout the grazing lands as evidenced by the high degree of clearing, especially in coastal and sub-coastal Queensland (Department of Natural Resources 1999).

The initial benefits of tree clearing have been well documented. Non-leguminous trees and shrubs normally decrease pasture production within their projected tree canopies and beyond (House and Hall 2001). Documentation of higher pasture production in open areas compared with woodlands of Queensland include *Eucalyptus crebra* in north Queensland (Gillard 1979, Gardener *et al.* 1990, McIvor and Gardener 1995); *Eucalyptus* spp. in central Queensland (Walker *et al.* 1986, Scanlan and Burrows 1990); *Acacia harpophylla* in central Queensland (Scanlan 1991); *Eucalyptus populnea* (Walker *et al*. 1972) and *Callitris columellaris* (Wells 1974) in southern Queensland; and *Acacia aneura* (Beale 1973) in south-western Queensland. Shrub species have also been reported as decreasing pasture production including *Acacia nilotica* in north-west Queensland (Burrows *et al.* 1990); *Eremophila mitchellii* in central Queensland (Scanlan 1992); and *Eremophila gilesii* in south-western Queensland (Burrows *et al.* 1990). *Dodonaea viscosa* and *Cassia nemophila* in north-western New South Wales also show similar trends to shrubs in Queensland (Noble 1997).

1.3 Review of the effects of tree strips on pasture microclimate and other environmental factors

Tree strips are synonymous with the more commonly used terms of windbreaks, shelterbelts, tree belts, or banded vegetation. The terms differ mostly in their scale of application and the functional capabilities that are being sought by the land manager (e.g. microclimate response, stock shelter, protection from wind erosion). The term *tree strip* is used throughout this document for consistency. Tree strips have long been used as a mechanism for reducing wind speed and wind damage, providing shelter and beneficial microclimate change, increasing soil moisture and plant growth (Judd *et al.* 1996, Wang and Takle 1996, Cleugh 1998). It is only in more recent times, however, that systematic studies have considered the aerodynamics and shelter mechanisms of tree strips in a quantitative manner (Wang *et al.* 2001). Existing theory on the aerodynamic properties of tree strips, and their subsequent effects on microclimate, soil properties and pasture or crop growth, suggests that similar responses occur at different sites, despite the variability in height, width, orientation, tree basal area, establishment and management histories, and soil and water properties between localities. The analysis of the tree strip studies in this report draws upon previously published studies (e.g. Judd *et al.* 1996, Cleugh and Hughes 2002, Cleugh 2003). We hypothesise that the mechanisms that underpin the physical response of wind, heat and moisture fluxes throughout a landscape are generally consistent in whatever landscape they are applied, although the extent to which a particular mechanism is dominant depends on tree strip orientation, and on local landscape and wind field properties.

How tree strips affect aerodynamic properties

The aerodynamic properties of tree strips affect wind speeds, directions and the turbulence of the air flow (Cleugh 1998). The basic influences of tree strips on pastures is through the shelter they provide by reducing wind speeds, which is primarily determined by the drag created by the canopy of trees/shrubs and the growth and decay of the turbulent mixing layer. The point just before and above the tree strip at which the wind field diverges is termed the *displacement zone*. The displaced wind profile is the result of an inflection (wind shear) above the canopy, above which wind speed increases logarithmically with height when the atmosphere is neutral (Cleugh 1998). Vertically below this point, and on the lee side of the break, the wind speed decreases to some minimum (U_{min}) in what is termed the *quiet zone*. The displacement zone also marks a point of increased turbulence in the wind field, resulting in a *mixing layer* between the slower moving air below in the quiet zone and the faster moving air above (Cleugh 1998). Where strong downward mixing is present, this is referred to as *downward flux momentum*. The increased turbulence in the mixing layer also increases the vertical transport fluxes of heat and water vapour. It is the changes in these scalar fluxes which modifies the temperature, humidity and CO_2 of the air in the quiet zone. The *wake zone* is where the mixing layer contacts the ground, and thereafter reaches an *equilibrium zone* where the wind speed and turbulence profiles are returned to upwind values. Turbulence and transfer of scalar fluxes is reduced in the quiet zone and enhanced in the wake zone (McNaughton 1988).

Different tree strip heights, porosities, width, and up-wind turbulence, all affect the profile of the mixing layer and the subsequent location of U_{min}. As tree strips are porous to some extent, wind will still pass through in what is termed *bleed flow*, which also affects the position of U_{min}. The position of the equilibrium zone on the lee side of the tree strip also varies, but is usually dependent on the height of the tree strip. The different zones discussed above are usually based on the distance (H) from the tree strip in terms of multiples of tree heights (Z). These are shown in Figure 1.1.

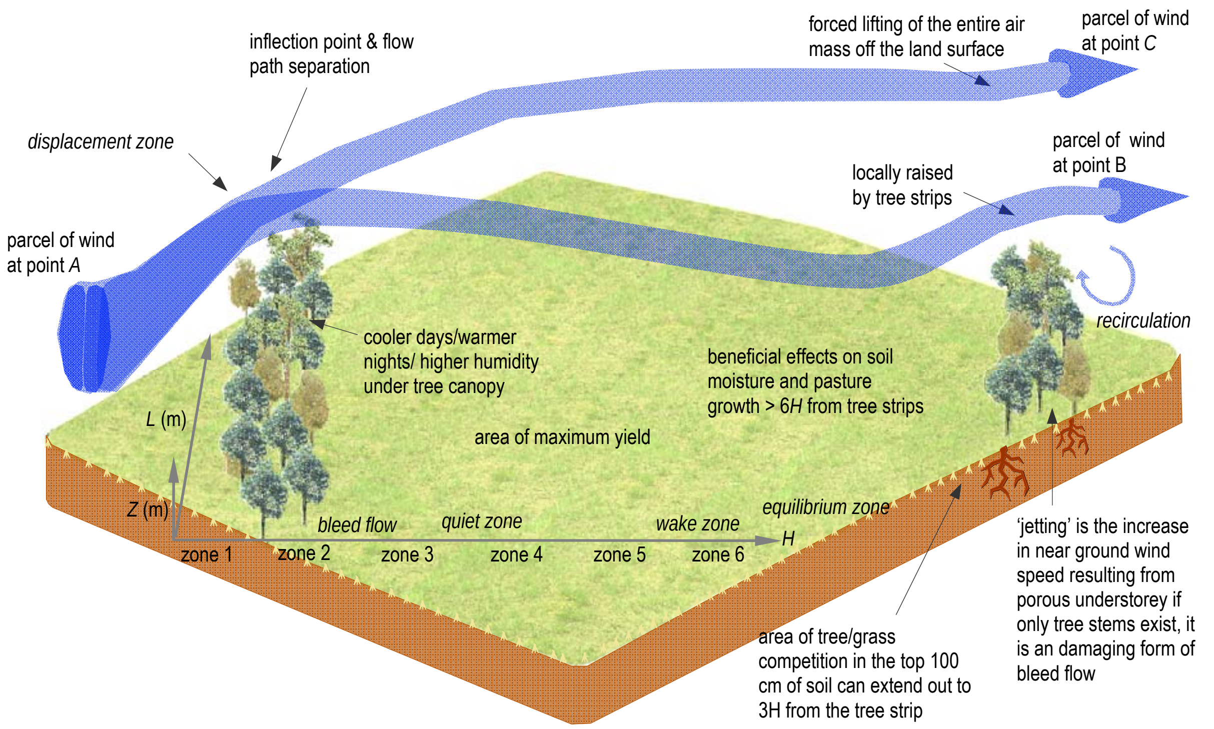


Figure 1.1. Conceptual model of aerodynamic properties and terminology for windbreaks. The zone numbers indicated along the bottom of the horizontal axis shows the zones used in this report, other labels are general terminology used in windbreak studies. Note that we hypothesise two possible effects of tree strips on wind profiles when multiple arrays are encountered across a landscape: i) localised disruption; ii) forced lifting of entire air mass off the surface of the landscape (J. Ryan unpublished).

Main determinants of tree strip performance

The most commonly described properties of tree strips that affect their performance as a windbreak and modifier of microclimate, soil moisture and plant growth, are height, porosity and upwind turbulence. These and other important factors that will be discussed are:

- tree strip height;
- tree strip porosity;
- upwind turbulence;
- length of tree strips;
- orientation of tree strips;
- multiple arrays of tree strips; and
- physical structure of trees and understorey plants used.

Tree strip height

The height of the trees in the strip is the main determinant of downwind extent of shelter provided (Cleugh and Hughes 2002, Cleugh 2003). The height of the tallest trees provide the bulk of protection from wind, as height directly affects how far downwind the turbulent layer re-establishes contact with the ground. A large wind shear is created at the top and immediately downwind of tree strip, which is proportional to the height of the trees (Cleugh and Hughes 2002). This is also where the mixing layer is initiated. The position of the equilibrium zone on the lee side of the tree strip varies due to tree strip height, and to a lesser degree up-wind turbulence. Some studies have shown this to occur at approximately 2.5*H* (Judd *et al*. 1996), 4-8*H* (Wang and Takle 1997), and in some cases greater than 10*H* (Cleugh 1998). Wind speeds usually recover to ~ 80% of their up-wind values by 20*H*, and completely by ~ 30*H* (Cleugh 1998). The actual distance depends on the height of the tree strip – the taller the trees, the greater the distance of protection extended downwind.

Tree strip *porosity*

A tree strip's optical porosity (β) is defined as the ratio of open areas to that of vegetated obstructions (Judd *et al.* 1996), or the amount daylight that can seen through it. Aerodynamic porosity (ϕ) is the amount of obstruction encountered by the wind, which can be greater than optical porosity as wind passing through a canopy involves three dimensional flow. This particularly occurs when wind direction becomes increasingly oblique to tree strip orientation (Cleugh 1998) and is the main determinant of the level of reduction in wind speed obtained by the tree strip (Judd *et al.* 1996, Cleugh 2003). As the porosity of tree strips reduces, the location of the zone of maximum wind speed reduction (U_{min}) shifts back toward the tree strip, which will also cause greater changes in temperature and humidity changes (Cleugh and Hughes 2002).

Nuberg (1998) considers that the semi-permeability of tree canopies actually reduces the kinetic energy of the wind. Wang and Takle (1997) suggest that reductions of wind speed and resultant shelter are not only determined by the total drag exerted by tree canopies, but also by the distribution of the drag-generated momentum deficit within the sheltered area.

Results from the National Windbreaks Program confirm that porosity, as manifested through the windbreak's foliage density, directly affects the level of wind speed reductions that can be gained (Cleugh 2003). For example, porosities of 70% porosity reduced maximum wind speed by approximately 40%, whereas 30% porosity reduced wind speeds by 75%. If porosity is very low (e.g. 10%) some recirculation of wind is possible. Wang and Tackle (1997) consider that medium-dense tree strips may result in the maximum shelter possible at a site, which may arise as a result of the pressure gradient and advection transport processes. Cleugh (1998) suggests that for porosities between 10-50%, no discernible difference is evident in the extent of shelter provided by tree strips.

Up-wind turbulence

Many studies have confirmed the significance of up-wind surface features on the performance and extent of shelter provided by windbreaks further down-wind (Judd *et al.* 1996). Topographic features such as hills or large vegetation patches across the terrain will affect the turbulence of the wind field before it reaches the windbreak, which in turn, can change the position and reduce the extent of the quiet zone on the lee side of the windbreak (Judd *et al.* 1996, Cleugh and Hughes 2002, Cleugh 2003). This is partly due to the fact that increased turbulence assists the mixing layer to return to up-wind values in wind speeds (i.e. the *equilibrium zone*). This means that the performance of tree strips in open landscapes will differ from those in more forested or undulating landscapes (Cleugh and Hughes 2002).

Topographic position has been shown to be an important factor determining the turbulence in wind fields. Local breezes can form from differential heating on slopes facing north to those of southern aspects (Cleugh and Hughes 2002). For example, strips left along riparian areas are less likely to suffer damage from winds flowing down a valley (Ruel *et al.* 1998), although strips perpendicular would cerate more resistance to the flow of wind. Likewise, strips placed on hillcrests and saddles are more likely to be affected by high winds, but provide greater turbulent flow further down the slope (Cleugh and Hughes 2002). This is important for sites such as Duke's Plain, where topographic relief in the form of a low range to the southeast is likely to have some effect on the local performance of the tree strips.

Tree strip length

Cleugh (2003) suggests that the length of the tree strip is important as it directly affects how much protection is afforded on the lee side of the strip when winds are blowing at angles other than perpendicular. Cleugh (2003) also states that as long as the length of the tree strip is more than 20*H*, effective two dimensional flow occurs through and over the tree strip. Shorter tree strips may still be effective, although the quiet zone may be smaller and more elongated when the wind is blowing obliquely across them (Cleugh and Hughes 2002). The effective length of tree strips can be increased by configuring them with existing remnant or agroforestry patches.

Tree strip orientation

Orientation of the tree strip in relation to the wind direction is important as it will affect the shape and extent of the downwind area sheltered from the wind. In a numerical simulation, Wang and Takle (1996) found that horizontal profiles of wind speed and the location of the zone of maximum wind reduction (i.e. quiet zone) moves toward the tree strip when approach flow departs from perpendicular. In addition, they also suggested wind speeds may actually increase when blowing parallel to strip orientation because of the channelling effects, although some reduction in wind speed may along canopy edges due to frictional forces. The surface flow of wind behind a tree strip is significantly affected by the orientation of the barrier relative to the wind direction, which becomes more important as the length-to height ratio decreases (Mulhearn and Bradley 1977). Cleugh (2003) considers that if the length of the tree strip is greater than 20*H*, then suitable protection can still be gained for wind directions up to 30 degrees from perpendicular to the tree strip.

Cleugh (1998) suggests that turbulent momentum fluxes are more sensitive to orientation regardless of porosity. While wind speed reductions may still be achieved in oblique flows, changes in scalar fluxes may not be to similar levels. For central and southern Queensland the most effective tree strip orientation will vary considerably from region to region depending upon the location of regional scale summer synoptic patterns and local scale topographic and vegetation features. Where wind records are not available from a nearby BOM station, local property records or observations may be suitable surrogates.

Multiple arrays of tree strips

Cleugh (2003) suggests that multiple arrays of tree strips are needed to obtain maximum protection and performance as a windbreak. The overall effect of multiple tree strips is for a greater area of protection than for single isolated windbreaks because of the 'non-local' effect related to increased turbulence (Judd *et al.* 1996). In other words, the effect of multiple tree strips in array is cumulative (Cleugh 2003). This means that as more of the landscape is covered by tree strips, wind speed reductions are achieved over much broader areas than would be the case for one or two tree strips alone. It is important to note, however, that multiple arrays of tree strips actually decrease the protection given by any one tree strip's quiet zone, while increasing the size of turbulent wake zone (Judd *et al.* 1996).

Most locations exhibit highly variable wind directions so it is not possible to orientate tree strips to cover all possible directions. There are two alternatives according to Cleugh (2003): 1) orientation to prevailing wind based on property records of wind (or local observations); and 2) multiple tree strips aligned along paddock boundary fences. To intercept the most damaging and drying winds, in summer growing pastures such as in southern Queensland, tree strips may function best when aligned perpendicular to the direction of prevailing wind at either 9 am or 3 pm for January at a given location.

Physical form of plant species

The actual physical form of the trees also plays a role in their ability to reduce wind speeds. As tree strips are porous to some extent, wind will still pass through in what is termed *bleed flow*. However, without adequate density in the lower layers of the tree strip, wind speeds can actually increase as it passes between tree stems in a process termed *jetting* (Judd *et al.* 1996, Nuberg 1998). The prevention of jetting and the gaining of both maximum wind speed reductions and large extents of shelter, requires tall and dense tree strips which excludes browsing by stock (Bird *et al.* 2007). Adding a shrub layer provides maximum benefit, provided stock are excluded from grazing the windbreak (i.e. fenced) (Cleugh 2003).

Trees with a low leaf area index (LAI) and thin stems will be of little value compared to species with larger LAI and biomass. Conversely, increased LAI also increases water use through evapotranspiration. Photosynthetic rate, LAI, stomatal conductance, net primary productivity and the accumulation of biomass are related to long-term rainfall, atmospheric CO_2 levels and soil nutrient and moisture status. For native tree species, increasing aridity and solar radiation reduce stomatal conductance and LAI, while increases in nitrogen content per unit leaf area are associated with increases in stomatal conductance (Farquhar *et al.* 2002, Pitman *et al.* 2004). Thus soil fertility may also affect the impact of tree strips through effects on leaf area.

The physical form of the tree species will also affect the degree to which there are competitive and complimentary effects between trees and pastures. Studies suggest that species such as *Eucalyptus tereticornis* and *E. viminalis* are very competitive, while others such as *E. camaldulensis* are less competitive (Bird 1998, Nuberg

1998). In some cases *E. camaldulensis* has been suggested to recycle deep nutrients (e.g. N, K, Ca, Mg, Na) back into leaves and eventually to the soil as leaf litter. Many semi-arid and sub-tropical African countries have utilised species such as *Casuarina cunninghamii*, *Grevillia robusta* and various *Acacia* species. Locally adapted species are usually most resilient to drought and offer some provision for the conservation of biodiversity.

Microclimate effects

Tree strips are well coupled with the atmosphere (Smith and Jarvis 1998), so the effect on wind speed is only one of the processes through which tree strips modify evaporation, humidity and soil moisture (Cleugh 1998). The major effects on the microclimate surrounding a windbreak are also strongly regulated by turbulent exchanges of heat and moisture fluxes in the quiet and wake zones on the lee side of the strip (see Figure 1.2). It is this turbulent mixing layer which is responsible for directly affecting temperature, humidity, and CO_2. As wind speeds directly affect the level of modification to temperature, this means, that provided the changes in temperature can be accurately recorded, reductions in wind speed can also be estimated.

During the daytime period, the quiet zone usually has higher temperatures and humidity due to lower turbulent exchange with lower atmosphere, while the increased turbulence in the wake zone often results in lower temperatures and humidity (McNaughton 1988). By night these trends may reverse, or even during different seasons. The exchange of water vapour shows a similar trend, while levels of CO_2 in the quiet zone are usually only slightly reduced and have no real effect on plant photosynthesis (Brown and Rosenberg 1971). Small changes in temperature, however, can have marked impacts on plant physiology and phenological timing (Ivory 1975, Nuberg 1998). The porosity of the tree strip will also affect the level of microclimate modification, with highly porous strips having little benefit (Cleugh and Hughes 2002). The extent to which a tree strip can modify humidity is also dependent on the saturation deficit of the regional air.

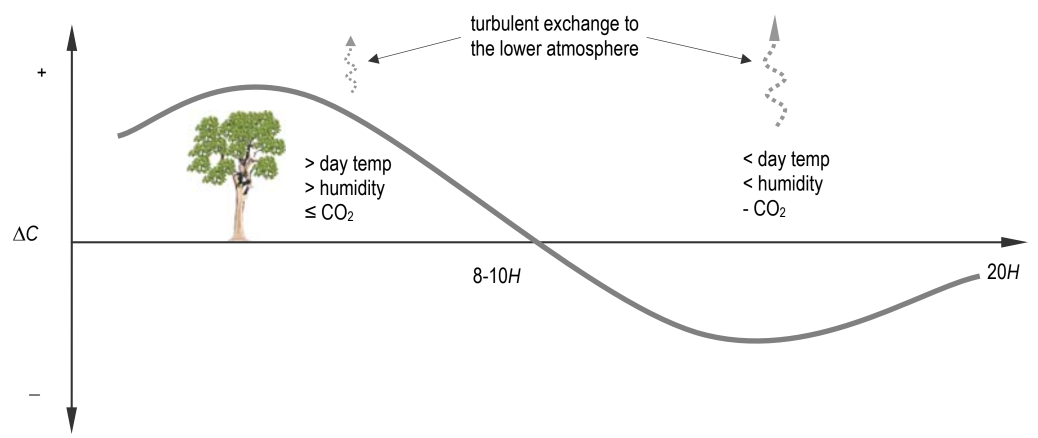


Figure 1.2. A general model of the response and relative strength of change (Δ) of scalar fluxes (*C*) when wind speed is perturbed around and over a tree strip (adapted from McNaughton, 1988).

Other microclimatic effects relate to shading adjacent to the tree strip. Some research suggests that shading can reduce growth or increase shoot/root ratio of grasses, but this may be more relevant to pasture grasses than for legumes (Ludlow *et al.* 1974). In another study by Wilson (1996), shade appeared to stimulate shoot dry matter yield by up to 37% in Green Panic, 22% in Rhodes grass, and 9% in Speargrass. Buffel grass yield on clay soils decreased but showed no change on a granitic soil, while nitrogen content increased by 39% on the later soil type. During winter, shading may increase the likelihood frost if the tree strips pool cold air flowing down a slope (Bird 1998). Other benefits of shading may be related to the preservation of soil moisture by reducing extreme soil temperatures during hot weather and increased soil organic matter leading to better plant nutrition.

Effects on soil moisture

Nuberg (1998) suggested that plants will develop deeper and more drought tolerant roots due to increased soil moisture from wind reductions and shading. The effects on soil moisture, however, may be masked by changes in soil texture across a landscape (Bird 1998). This variability may also mask the beneficial effects of tree strips. Plant response may actually be due to improved nutrient status more than increases in soil moisture, resulting from increased organic matter, deeper nutrient recycling, and nutrient enrichment as a result of livestock camping in or along the tree strip. As mentioned above, the species of tree used will partly determine the moisture and nutrient tradeoffs and benefits including the competition for soil water through tree root architecture. Bird (1998) suggest that soil moisture status will be more important for C3 than for C4 grasses which operate efficiently even when stomatal aperture is reduced.

Effects on plant growth

The beneficial effects of wind breaks on pasture/crop microclimate result from reductions in wind speed leading to more favorable conditions of temperature, humidity and potential evaporative demand. The microclimate effects improve plant water use efficiency by lowering evaporative demand and reducing damage to leaves (Cleugh 1998, Nuberg 1998). A summary of results from the National Windbreaks Program based on Cleugh (2003) and the case studies in this report are provided in Table 1.1.

Table 1.1. Summary of case study findings for microclimate effects of windbreaks (from Cleugh 2003, Sudmeyer et al. 2002).

Location	Height (m)	Windbreak width/ length (m)	Windbreak porosity (%)	Max wind reduction (% / H)	Extent of wake zone (H)	Temp (0C) changes day/night	Max extent of tree roots (H)	biomass-yield change/ extent (%/H)
Bungendore, NSW	6-7	-/1000	15-20	60/6	25-30	+2	-	-
Hamilton, Vic								
site a.	-	-	-	68/4	23	+0.8/-0.4	<1	+9/-
site b.	-	-	-	65/5	30		-	
Roseworthy, SA	9	-/1000	-	55/6-9	24	-	-	+11/24
Esperance, WA								
windbreak	10	-	-	47/3-6	36	-	3-5	+15-20/20
artificial shelter	-	-	-	-	-	+0.9/-0.4	-	-
Warwick, Qld								
artificial shelter	-	-	-	-	-	-0.5/+0.3	-	-
Atherton, Qld	-	-	-	-		-	-	potatoes +9.5/18
Survey of SW- WA	-	-	-	-	-	-	-	+25/40
Survey of S.A	-	-	-	-	-	-	-	pulse crops +11/- wheat +7/-

Evaporative demand

Tree strips reduce the potential evaporation of water from the soil and transpiration losses from plants, and improves their water use efficiency (Bird 1998). These factors can result in increased growth of plants, which conversely, can increase actual transpiration from the increased biomass. Thus there may be little overall impact on soil moisture. Many differences in response are explained by the air saturation deficit (vapour pressure deficit), stomatal resistance of a plant's leaves, and light, temperature and moisture stress (Cleugh 1998). Gradients in humidity between the interior of leaves and air in contact with leaf surfaces drive the transfer of vapour from vegetation to the atmosphere by the diffusion of water vapour through stomatal pores (Smith and Jarvis 1998). Trees have a much greater control over stomatal aperture than grasses or crops, and can retain canopy cover during extremely dry conditions.

Reductions in wind speed may only reduce evaporation when it exceeds the equilibrium evaporation rate, which is dependent on the leaf-air humidity gradient and critical stomatal resistance. If wind speeds are lowered, this will increase the temperature of leaves and the leaf-air pressure gradient leading to increased transpiration. Where dry air advection is a dominant process, however, reducing wind speed will reduce evaporation. Landscapes which suffer periodic hot, dry and windy conditions are therefore, likely to benefit from tree strips as they improve plant water use efficiency by reducing rate of moisture loss (Nuberg 1998).

Biomass and yield

Cleugh (2003) summarised a large number of field trials in the National Windbreaks Program which pointed toward general improvements in plant growth and yields over a range of climate and soil regimes. This did not always translate to increases in yield (for crops). This may be due to plants favouring vegetative growth over that of reproductive growth (e.g. flowers, fruit Nuberg 1998). Maximum response of plants in terms of biomass and yield usually occurs in the quiet zone (3-10*H*). Increases in yields have been stated across a wide range of climatic zones, temperate, sub-tropical, semi-arid and mediterranean climatic zones, but the mechanisms responsible may vary for hot or cold regions (Nuberg 1998). For example, for broad-leaved crops and fruit it seems that direct benefits stem from reduced leaf damage and abrasion from sandblasting. Where sandblasting affects crop growth and yields, windbreaks have increased production by as much as 25% out to 40*H* from the tree strip (Cleugh 2003). Cereal crops do not appear to be a responsive to shelter effects from protection from wind, perhaps because there is more stalk and less leaf area.

Tree-grass competition presents the major limitation to gains in pasture production. Direct competition for water and limiting nutrients is more likely to occur on poorer soils and in drier conditions, although conversely, these are the same environments in which protection from wind may see the greatest gains in biomass of pasture grasses. Competition between roots and pasture grasses generally occurs in zones 1-3*H*. Root pruning through deep ripping can be used to control tree roots along the drip line, which has been shown to be very effective in reducing competition with pastures and crops. Another potential negative effect that can also arise from some tree species is the presence of allelopathic chemicals which are toxic to other plants (Cleugh 1998).

Health and nutrition

The main effect on health is through physical protection from damage due to wind. This includes sand-blasting, tearing or removal of leaves, and bending, lodging or breakage of stems (Sudmeyer *et al.* 2002, Cleugh 2003). It has been suggested that tree strips can enhance the palatability of pasture grasses (Jackson and Ash 2001). This was also stated as being the reason for cattle preferentially browsing under Brigalow trees trips at Dukes Plain (S. Joyce *pers. comm*.). Another potential beneficial effect of tree strips, particularly Brigalow, is for enhanced soil biological activity to improve nutrient availability to plants (Fyfe in prep.). Birds that predate on damaging insects is another ecological factor which is enhanced by tree strips through the provision of shelter, food and nesting sites (Cleugh 1998).

Effects on livestock

Shelter from tree strips can affect stock in a number of ways. These effects can be direct or indirect. Direct effects are related to the increased thermal comfort of stock through protection from the wind, intense summer heat or winter cold (Dronen 1988, Bird 1998, Jones and Hennessy 2000). The effect of shelter on livestock in central and southern Queensland may not be as important as it is in southern regions, as winters are mild while cattle are robust even in very hot conditions. Nevertheless, animals do seek shade where it is available and adjacent to water (Daly 1984).

Tree strip and landscape design considerations

Tree strips may not be profitable simply for their shelter functions. However, the other benefits may offset the loss of production from competitive effects and loss of pasture area. Measuring or estimating the value of the multiple functions of tree strips, however, is only possible where climatic, hydrological, soil, topographic and vegetation effects are considered together. To integrate these variables in a consistent manner requires specific measurements of the corresponding heterogeneity in topography, soil types and runoff distribution. Objectives therefore should consider protection from wind, interception of rainfall, infiltration of water to depth, capture of overland flow and deposition of coarse sediment, and enhancing local humidity and convection which may further invigorate precipitation recycling mechanisms. This is illustrated in a conceptual model in Figure 1.3. Some of the potential benefits of tree strips for both production and landscape functioning are provided in Table 1.2.

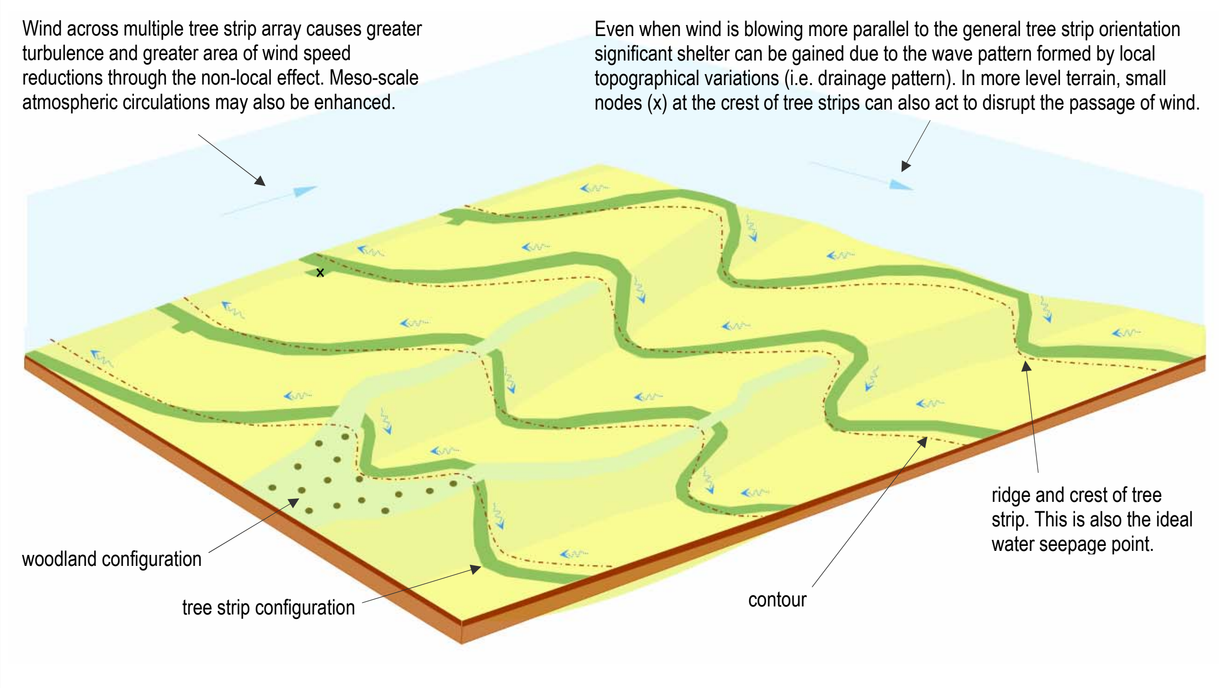


Figure 1.3. A simple tree strip configuration with integrated functions designed to intercept and redistribute overland water flows more evenly across slopes, provide shelter from wind and buffer against hot and dry conditions, facilitate meso-scale circulations, and provide links for biodiversity. Dotted region in the lower waterway is a woodland configuration which may be more appropriate in dryer more open semi-arid landscapes or in areas prone to periodic inundation. The transition between tree strips or woodlands is therefore, related to rainfall or landscape position (see Figure 1.4) (J. Ryan, unpublished).

Table 1.2. Functions and benefits of tree-strips for agricultural productivity and catchment functioning (from Cleugh 2003, Ryan 2007, 2008).

Functions	Production Benefits
Microclimate buffering (< wind, < daily max, > daily min, > humidity)	Increased pasture production
Decreased wind erosion	Provision of shade/shelter for animal production
Improved soil properties (> organic matter, > soil moisture, > infiltration)	Less physical damage to plants
Enhanced ecohydrological functioning (> precipitation recycling)	Plant knockdown (lodging)
Reducing evaporative water losses from dams and waterways	Timber and other tree products
Control of erosion by water (when combined with grassed filter strips)	Fodder source
Control of water-logging and dryland salinity	Aesthetics
Habitat for biodiversity	

Insurance against land degradation

During extended dry periods, depleted pastures have minimal biomass which exposes more soil to compaction and wind and water erosion, and creek banks become fragile and mobile. Effective land management, therefore, must accommodate the impact of extreme events which are likely to be the most damaging (Bird *et al.* 1992). In this case, tree strips may be regarded as a form of insurance Sudmeyer *et al*. (2002). Even in landscapes which are already 'degraded' from long-term (years) exposure to hot-dry winds, can be reclaimed from 'desertification' by multiple tree strips (shelterbelts) (Cleugh 1998, Stigter *et al.* 2002). Soil erosion from wind in particular can have deleterious impacts in some landscapes, and this is most marked on light poorly structured soils that are dry at some part of the year. For example, dust can have up to four times the nitrogen, eight times the phosphorus, and ten times the organic matter content compared to the soils from which it was derived (Nuberg 1998).

Multiple scales for multiple functions

When considering these factors, however, multiple scales must be taken into account in order to adequately address both larger overriding climatic processes as well as smaller scale soil and water processes. The spatial configuration of different components of land cover directly and indirectly affect wind directions and speeds, humidity, air temperatures, radiation partitioning between sensible and latent heat fluxes, albedo, soil moisture, localised turbulence and convection, and the formation of cumulus (Lyons *et al.* 1996, Hayden 1998, Saunders *et al.* 1998, Ray *et al.* 2003, Baldocchi *et al.* 2004). This becomes an important factor when considering the cumulative effects from removing large areas of woodlands for grazing over many decades. For example, McAlpine *et al.* (2007) suggested, from simulated studies, that decreases in rainfall of approximately 8-12% have occurred in northern NSW and SEQ due to incremental broad-scale changes in land cover over the prior 50 years. It is suggested that broad areas of forested land may increase local rainfall due to the return of water vapour to the lower atmosphere via evapo-transpiration sources in conjunction with regions of focussed convection (Anthes 1984, Savenije 1995, Yiqun Zheng 2002, Osborne *et al.* 2004). Some researchers have termed this as *precipitation recycling* (Pal and Eltahir 2001).

Tree strips can also affect the ecohydrological functioning across a landscape. Depending on their orientation, there will be effects on local runoff, run-on, drainage and detention across individual paddocks. Often when the initial canopy cover is removed over large areas there is less interception of rainfall, a slow decline in soil structure and fertility, less cycling of soil moisture, and more extreme runoff events (Elliot and Ward 1995, Martinez-Mena *et al.* 2000, Magdoff and Weil 2004, Williams and Saunders 2005). This is partly due to the fact that many native trees have structures which efficiently direct rainfall into the soil due to their branching habits which causes water to be intercepted, directed down the trunk and infiltrated to considerable depths at the base of the tree (Hatton and Nulsen 1999).

In field experiments using a rainfall simulator, (Ellis *et al.* 2006) found that tree strips (belts) gained up to 37% more water above incident rainfall. This represents a substantial additional store of soil moisture and nutrients available to plants within the tree strips able to be redistributed. Ticehurst *et al.* (2005) investigated the effect of tree strip designs on overland and lateral sub-surface flows on hillslope in the Billabong Creek Catchment, Holbrook, NSW. Ticehurst *et al.* (2005) suggested that shallow lateral flow paths are intercepted by tree strips, but this effect will vary depending on antecedent soil moisture and the intensity of the precipitation event. Recent simulation modelling by Ryan (2007) in the Maronghi Creek catchment in SEQ, suggested that tree strips in particular configurations can reduce the magnitude of stormwater runoff and erosion through increased entrainment, infiltration and storage at depth, which subsequently aids in the rehydration of landscapes.

To obtain these additional benefits of tree strips, however, requires careful consideration of local soil, topography and intensity of thunderstorm events. To provide the necessary entrainment, filtering and infiltration of water across hillslopes requires a water and sediment sink with adequate cover of high density and biomass from drought-tolerant tussock type grasses, sedges or reeds (Karssies and Prosser 1999, Carey *et al.* 2000, Hook 2003, Wang *et al.* 2004). Tree strips can add to the palatability of pasture grasses (Jackson and Ash 2001), however, if the additional organic matter within the tree strip is subsequently removed by grazing or fire, this may decrease infiltration and increase the risk of erosion (Scanlan 1992).

Tree strip or woodlands?

As conditions in a landscape become more arid, however, the form of protection may change from tree strips to scattered woodlands. Stigter *et al.* (2002) suggested that scattered trees may be more suitable than tree strips for intercropping under various wind profiles in arid lands. An alternative is to place woodlands between tree strips. A conceptual model of the natural phase transition between tree strips to that of either woodlands, groves or patches, is provided in Figure 1.4. Here the applicability of tree strips is based on a rainfall gradient, where decreasing rainfall results in increased width of the tree strips. These systems assume these strips are fenced and grazed only occasionally.

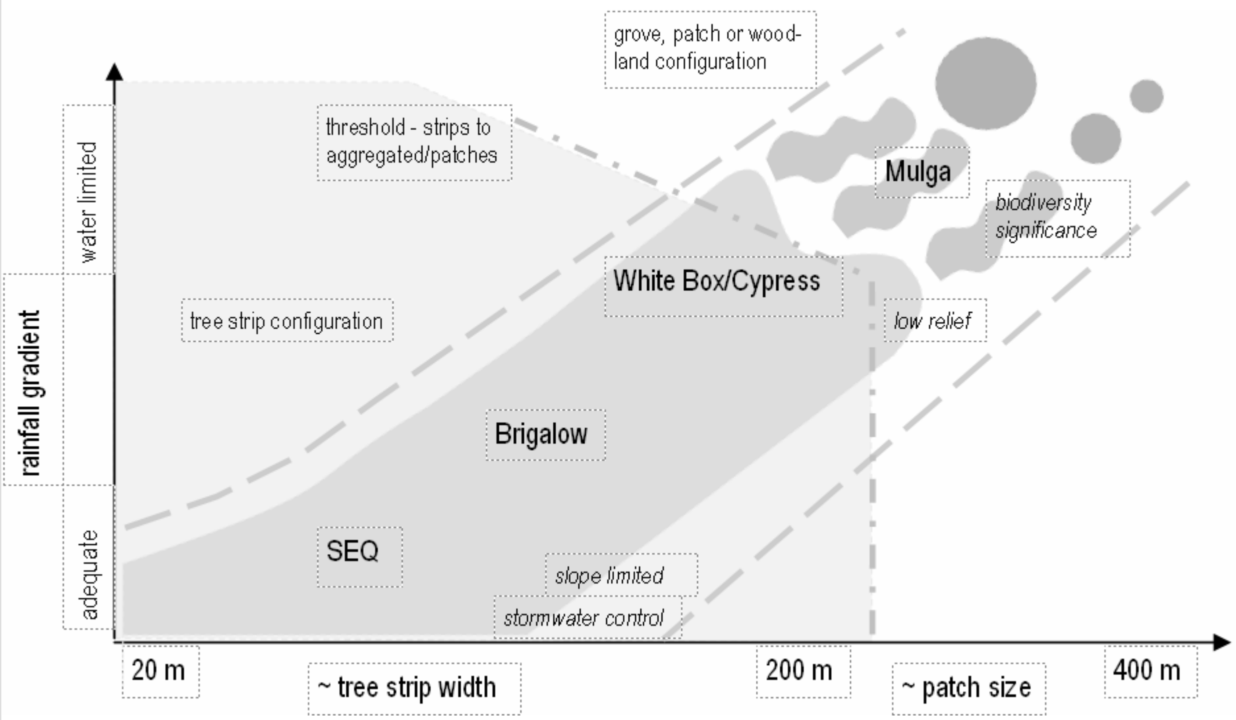


Figure 1.4. Concept of a natural phase transition between vegetation strips and groves/patches (J. Ryan unpublished).

Conclusion

While there is ample anecdotal evidence from around the world that tree strips (i.e. windbreaks) may have a net neutral or slightly beneficial effect on crop or pasture growth, this needs to be quantified in economic terms. Graziers/farmers need to be able to assess the real production gains from the retention and management of tree strips (Nuberg 1998). The quantification of these effects, however, is difficult due to two major confounding factors which are widely reported from windbreak studies (Bird 1998): 1) the inability to accurately account for the high variability in soil properties that occur across the site; and 2) the difficulty of attributing cause of observed response to particular mechanisms as there are multiple interactions between the tree strips, atmosphere, soil and plants which vary in dominance depending on a number of environmental, soil or vegetative factors.

Using regrowth vegetation to form self-sown tree strips would appear to be one of the most economical management options available for enhancing the function of climatic and ecohydrological systems at a landscape scale (Farrington and Salama 1996). The challenge is to find the right balance - the right tree strip or other configuration in the right place. The following study describes initial field experimentation to evaluate some of these effects.

1.4 Project Justification

The National Windbreaks Program (Prinsley 1992) went to considerable effort to quantify the benefits of windbreaks on dryland farming, crops and pasture performance in temperate agricultural systems. A volume of the journal Australian Journal of Experimental Agriculture (2002 Volume 42) contains 18 papers describing detailed field and modelling studies. Anecdotal and experimental evidence over the past 50 years suggests that windbreaks may improve crop, pasture and animal production (Cleugh *et al.* 2002). The reported studies emphasised the importance of modelling to help address the difficulty of field measurement and to help extrapolate experimental results. However, there is little experimental evidence for the subtropics and tropics of Queensland with regard to native and naturalised pasture production in relation to tree strips.

Many desirable aspects of retaining natural vegetation will be those that benefit the whole of society. In an environment of economic survival, many landholders are forced into making individual decisions that may be beneficial (essential) to them in the short-term but which are disadvantageous to the wider community in the longer-term. Reduction of salinity risk is a common reason for retaining trees in agricultural landscapes. Increased deep drainage is likely to occur after tree removal. Quantifying the immediate benefits of tree retention on production will assist landholders to design a production landscape that best meets their needs and the needs of the catchment and the community.

In most situations tree clearing increases pasture and livestock production, but the long-term effects (both on- and off- farm) may not be apparent (Harrington 1993). Further, there has been little systematic research into the benefits of shade and shelter for pastoralism in Queensland. Unlike southern states of Australia, where past over-clearing has led to a greater appreciation of the role of trees in the farm landscape, the focus in Queensland has been largely on the means of clearing vegetation and controlling regrowth, while minimising soil degradation. A feature of Queensland woodlands is the high potential rates of regrowth that follow clearing. The retention of regrowth in tree strips is one option practised by some graziers in southern Queensland. Thus there is a need to address this gap in scientific knowledge on the role of trees, particularly tree strips, in southern Queensland.

In addition to the emerging scientific evidence of potential benefit from trees strips, some graziers had already taken the initiative to leave strips of regrowth. Thus, there was considerable interest and encouragement from the grazing community to carry out this initial investigation.

2 Project Objectives

2.1 Project Objectives

The purpose of this project was to quantify the effects of tree strips on pasture production, water balance and microclimate. Prior to this project the beneficial effects of tree strips on the surrounding grazing system and pasture production were often speculated on, but rarely quantified. Hence, up to now, these beneficial effects have been treated only in a qualitative manner, as they are more difficult to measure than competitive effects.

The project objectives were to:

1) Define in quantitative terms the beneficial and competitive effects of trees on surrounding grazing systems in southern Queensland;
2) Develop the modelling capacity (within the GRASP pasture growth model) which will enable evaluation of the impacts of different tree and regrowth configurations and management on grazing systems in terms of productivity and sustainability; and
3) Develop and publish tree and grass management guidelines and associated extension and education materials for beef producers and distribute the publications.

3 Methodology

3.1 Site description and experimental treatments

3.1.1 General description of the study area

Sites for this project were located on three grazing properties in southern Queensland. Two of the properties (Moombah and Mt Lonsdale) are located within the Queensland section of the Murray Darling Basin whilst the third (Duke's Plain) is located with the Fitzroy Catchment (Figure 3.1.1). The main enterprise is beef cattle production with the exception of Moombah where wheat is grown each year.

3.1.2 Research sites

3.1.2.1 Duke's Plain

Duke's Plain is an 8000 ha grazing property in the southern central highlands of Queensland 25km west of Cracow (25.30S, 150.30E). There are two distinct land types on the property: brigalow downs (*Acacia harpophylla*) and forest country, dominated by spotted gum (*Corimbya maculata*) and ironbark (*Eucalyptus* spp.). Two tree retention strategies were adopted in the experimental paddocks:

1) Narrow grass strips (ranging in width between 4 and 6m) containing young brigalow regrowth (up to 6 years old) ranging from one tree wide to a maximum of 6m wide; and
2) Wide grass strips (120m wide) containing strips of 20 year old brigalow regrowth approximately 20m wide.

The wide strip configuration was chosen for this experiment. The property is grazed by beef cattle, using a high intensity-short duration grazing system ('cell' grazing). The tree strips chosen for this experiment are in neighbouring paddocks, Replicates 1 and 2 in one paddock, and Replicate 3 in the adjacent paddock. The layout is shown in Figure 3.1.2. Botanical composition of tree and pasture components are given in Section 4.2. The site coordinates are 25^{o} 11.293, 150^{o} 04.984.

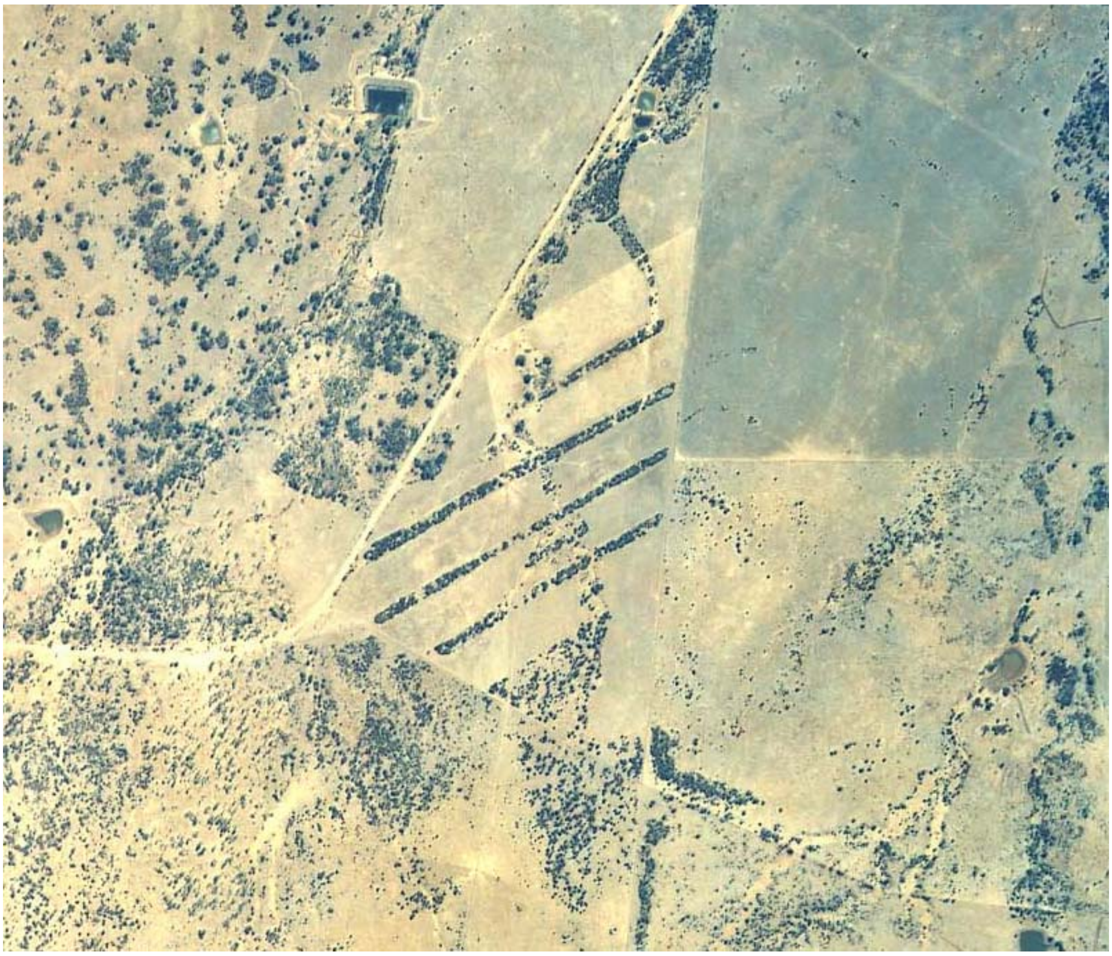


Plate 3.1.1. Image of Duke's Plain tree strips.

Figure 3.1.1. Location of the Study Sites.

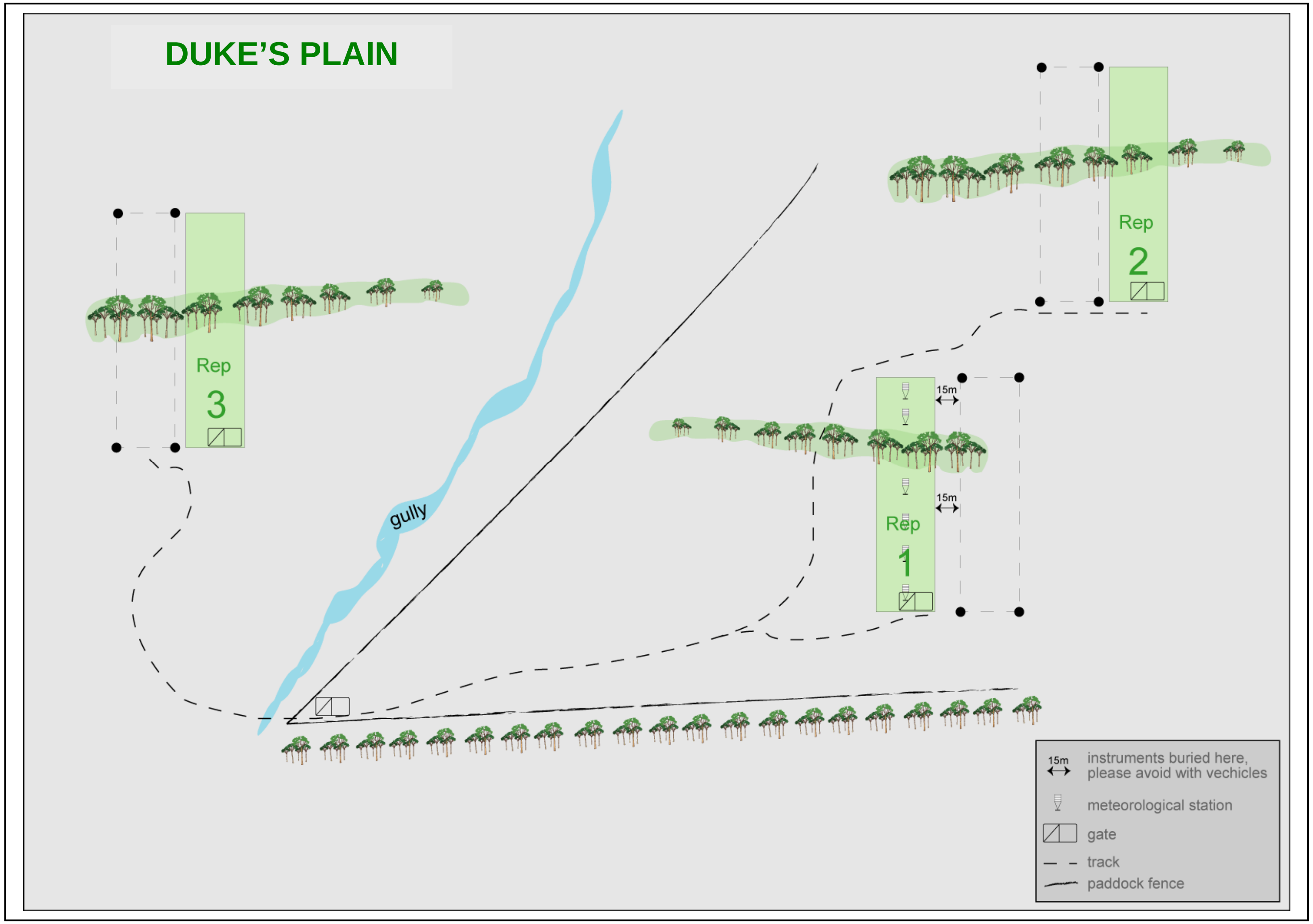


Figure 3.1.2. The site layout of Duke's Plain tree strips.

The grazier co-operator (S. Joyce) provided the following site history:

> Initial clearing occurred in 1964 with the Brigalow woodland being pulled and aerially seeded. This clearing was done as part of the Brigalow scheme with compulsory clearing as part of the lease conditions. In 1983, the trial area was blade ploughed and stick-raked. The orientation of the tree strips, i.e. south-west to north-east, was chosen to provide the maximum length of a blade plough run. The area between the tree strips was cropped from 1984 through to 1996. The crops grown were predominantly wheat with sorghum and millet as well. In one year, oats was grown as a forage crop. The current perennial pastures (buffel grass and native species) were **not** sown after cultivation, but were allowed to establish over a three year phase following cultivation. During this period, the area was part of a grazing cell using the stubble from the last crop. This was followed by a weed phase (Sida) and then an annual grass phase before the existing perennial grass stand developed. Changes in pasture composition are continuing to occur with buffel grass colonising country across the property. The replicate tree strips had the same orientation but there were important differences between the replicates in terms of the position (relative distance from each tree strip) of important pasture species such as Biloela buffel grass, Gayndah buffel grass and native species. In some diagrams in this report, Duke's Plain has been incorrectly referred to as the more colloquial term "Dukes Plains".

3.1.2.2 Mt Lonsdale

Mt Lonsdale is a 10,000 ha grazing property located 25km north-west of Mungallala (26.45S, 147.55E). The property consists primarily of poplar box soils and open bluegrass plains. The woodland design includes 20-year-old regrowth poplar box strips alternating with widely-spaced trees. The soils are classified as brown Sodosol (Isbell, 2002). The area between the tree strips was ringbarked in the 1920s and 1930s and cleared in the current configuration in 1997. All replicates were in the same paddock. The layout of the site is given in Figure 3.1.3. Botanical composition of tree and pasture components is given in Section 4.2. The coordinates of the site are 26^{o} 16.438, 147^{o}34.567.

The main trial area (i.e. cleared pasture transects) was between a tree strip of high tree density on the western side and an open box woodland on the eastern side. The area had been ringbarked in the 1920s and 1930s. The western side of the paddock was pulled in 1994 with retention of the tree strip of high tree density (Replicates 1 and 3). In Replicate 2 (low density of open box woodland), suckers were grubbed out in the early 1990s. The area was planted to buffel from the back of the tractor when pulling occurred, but because of the soil type, buffel did not establish well. The western side of the tree strip that formed Reps 1 and 3 was burnt in 2001. The eastern side (main pasture transects of Reps 1 and 3 and all of Rep 2) had not been burnt since the 1950s. The burning of the western side was for control regrowth and to get rid of the logs as this area is used to drive cattle along the fence. The open box woodland that formed the tree 'strip' component of Replicate 2, was regarded by the grazier co-operator (Bill Douglas) as "probably pretty much ideal" and hence only suckers were removed. In contrast, the trees in the western shade line were regarded as too thick.

Pulled timber was left on the trial area and was mainly parallel to the edge of treed area (strip and open woodland). In Rep 1, sections of the pasture transect had large variation in micro-topography associated with a linear Gilgai pattern running in a generally south-east to north-west direction through the pasture transect (Plate 3.2). Thus there was considerable variability between the replicates in terms of orientation, adjacent tree density, potential run-on from adjacent grazed areas, micro-topography, soil type differences and distribution of pulled timber through the pasture transect.

Plate 3.1.2. Tree strips and pasture exclosures at Mt Lonsdale.

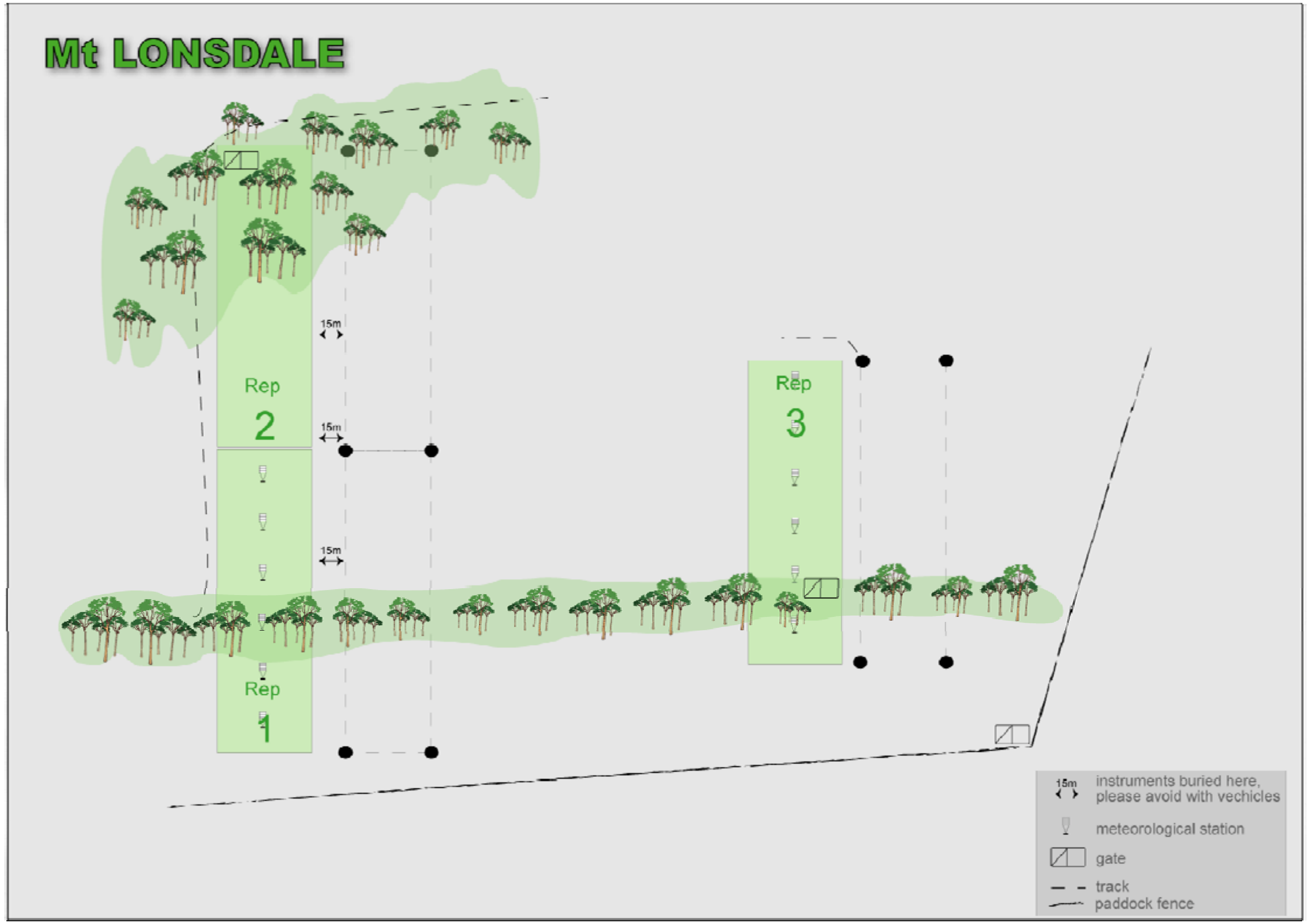


Figure 3.1.3. The site layout of Mt Lonsdale tree strips.

3.1.2.3 Moombah

“Moombah” (approximately 27.90S, 149.25E) is 60km north-east of St George. The tree strips were 400m apart with 100 m wide remnant strips of poplar box (*Eucalyptus populnae*), Wilga (*Geijera parviflora),* and false sandalwood (*Eremophila mitchellii*) with some cypress (*Callitris glaucophylla*). The layout of the site replicates is given in Figure 3.1.4. Botanical composition of tree and pasture components are given in Section 4.2. The coordinates of the sites are 27^{o} 53.603, 149^{o} 16.123.

The grazier co-operator (J. Kennedy) indicated that:

> Originally when the first Europeans came through the district, the country was open grassland with occasional trees with visibility for many kilometres in many directions. Over the last hundred years, probably due to reduced frequency of burning, relatively thick woody vegetation (shrubs and trees) developed (Plate 3.3).
>
> The trial area was cleared in 1999 and stick raked in 2002, and hence had only been sown for 12 months when the trial began. Importantly, at the time of the clearing and stick raking (1999), the 5-7m edge of the pasture adjacent to both sides of the tree strip was planted to buffel grass from a seed box on the back of the stick rake. The rest of the transect was not sown until several years later and after the fallen timber had been burnt. As a consequence, there was a higher density of buffel grass plants immediately adjacent (i.e. both sides) to the tree strips, and lower densities and two major ash beds, with associated fire effects through each replicate’s pasture transect. Thus, as described later, the location of peak pasture yield and the high variability in pasture yields measured along the transect were likely to reflect clearing and pasture establishment practices rather than tree strip effects themselves.

The pasture transect replicates varied in terms of: orientation (north and southern aspects); success of pasture establishment immediately adjacent to tree strip; and position of ash beds parallel with the tree strip.

Plate 3.1.3. Tree strips at Moombah.

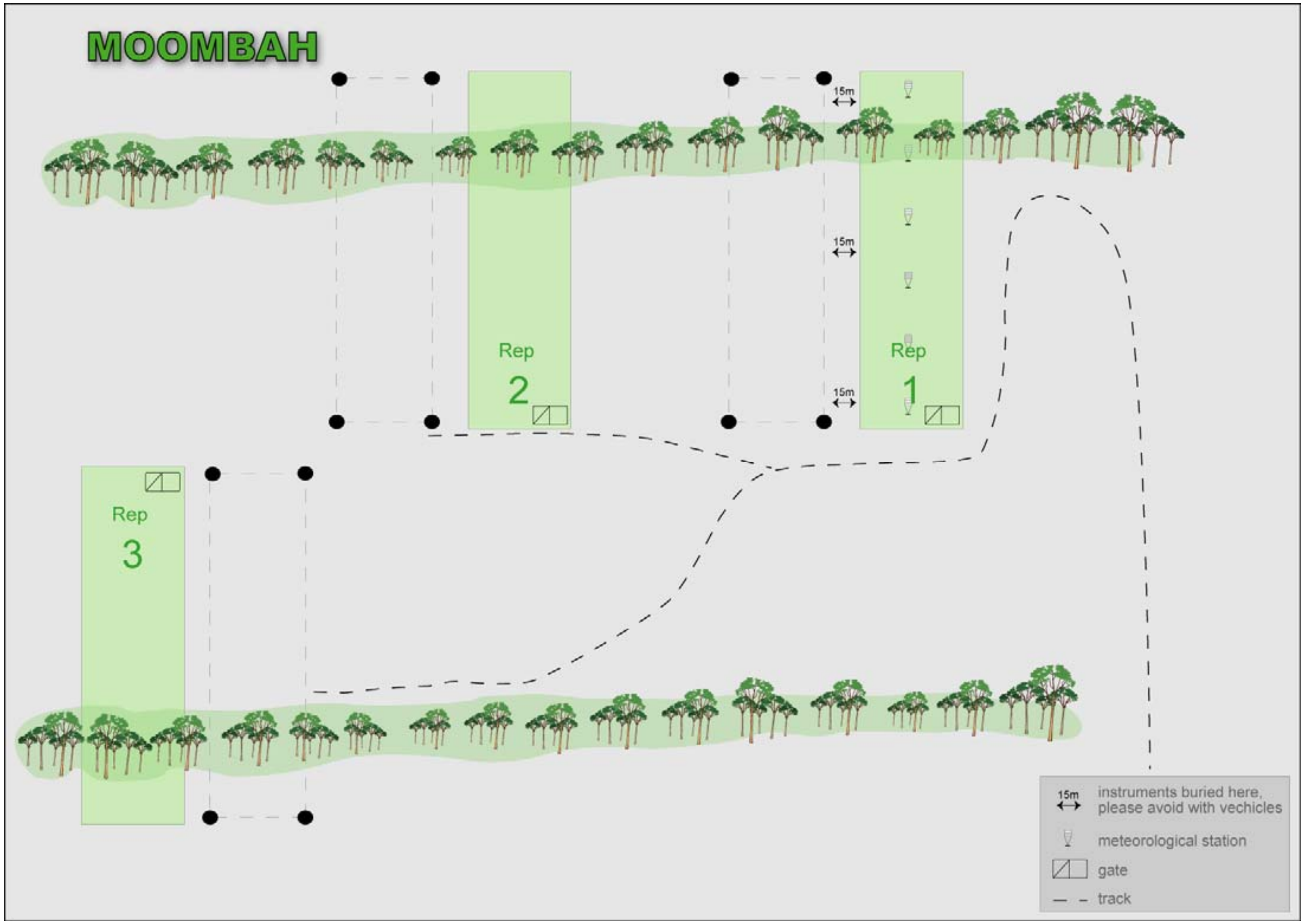


Figure 3.1.4. The site layout of Moombah tree strips.

3.1.3 Experimental treatments and sampling strategies

The research method we have used involved a combination of:

1) Paddock measurements of key processes. This involved the use of three field sites (Duke's Plain, Mt Lonsdale, and Moombah) each with three replicate tree strips, (including grazed and ungrazed treatments) with all measurements taken relative to distance from trees. Each replicate consisted of 6 zones (trees, edge of trees in both directions, beyond tree root zone, mid zone and open). Measurements of soil water content, soil nutrient and biological status and biota, microclimate, tree growth and water use, complemented annual measurements of pasture species, production and grazing effects.
2) Model parameterisation, validation and comparison to allow extrapolation of results. The details of the modelling approach and outcomes are described in Section 4.7.
3) Detailed interviews with grazier co-operators regarding their view on tree strips and management issues (not included in this report).

In order to evaluate both the competitive and beneficial effects of tree strips on the surrounding grazing ecosystem, the experimental design has used a number of zones relative to the dominant height of the tree strip (at the start of the experiment). Briefly these zones are

- Zone 2 was beneath trees, and was restricted to the canopy edge.
- Zones 1 and 3 were at the edge of trees on both aspects- in a zone at the edge of the tree strips to a distance half the height of the dominant tree type. Zone 1 was on the shortest side, with Zone 3 on the longer sampling side. The adjacent sides of the tree strips were included in the sampling design to test for the effects of aspect.
- Zone 4 was outside the immediate apparent impact of tree zone. This zone was adjacent to Zone 3, extending to a distance of 2 times the height of the dominant tree. It was hypothesised that this zone would be outside the immediate impacts of water competition for trees as tree root presence would be less than in Zones 2 and 3.
- Zone 5 was 'mid-zone', extending from the edge of Zone 4 to five times the height of the dominant tree.
- Zone 6 was open pasture being at the distance furthest away from tree strips, extending from the edge of Zone 5 to the point furthest from the tree strip, without beginning to approach any neighbouring tree strips.

In effect, Zone 6 became the control treatment, where the impacts of the tree strip in all the other zones could be compared. It was not possible to establish a 'true' control (i.e. treeless) on the properties, as treeless areas of equivalent size and soils were not available.

These zones were designed to measure the broad effects of tree strips across the paddocks, but were likely to be too coarse to measure subtle effects. Where this was believed to be the case, more detailed measurements were taken along a transect perpendicular to each tree strip. Detailed sampling procedures are described in later sections.

3.1.4 Tree strip orientation, tree attributes, zone and transect distance

The orientation of each of the nine tree-strip studies and the orientation of pasture transects are shown in Table 3.1.1. Pasture sampling transects, tree strip attributes and harvest dates are shown in Tables 3.1.2, 3.1.3, 3.1.4 and 3.1.5. The differences in tree and transect orientation provide contrasts allowing the testing of the variable potential influences of tree strips. For example:

1) Tree strips at Duke's Plain were relatively uniform, in terms of orientation south-west to north-east and pasture species, allowing estimates of tree strip influence with minimal 'real world' variability;
2) Mt Lonsdale strips had substantially different tree densities, particularly the low tree basal areas in Replicate 2 (Table 3.1.3). The orientation of the tree strip in Replicate 1 and 3 was north-south and hence the aspect of main pasture transects of Replicate 2 (west) was different to Replicate 1 and 3 (east); and
3) Moombah strips were east to west with two transects having a southern aspect (Replicates 1 and 2) and Replicate 3 having a northerly aspect.

The strips varied in width and tree height (Table 3.1.2). In the following analyses pasture transect data are reported in many cases in terms of multiples of tree height.

Table 3.1.1. Spatial orientation of tree strips, zones of measurement of tree influence and pasture harvest transect. Note A: The values at Mt Lonsdale for Reps 1 and 3 are not presented and are being reassessed to account for sampling anomalies.

Location	Replicate	Direction of tree strip	Aspect of Zone 1	Tree basal area of strip (m^2/ha)	Aspect of main pasture harvest transect Zones 3 to 6
Duke's Plain	1	South West to North East	South East	10.8	North West
	2	South West to North East	South East	20.6	North West
	3	South West to North East	South East	13.6	North West
Mt Lonsdale	1	North to South	West	A	East
	2	North to South	No Zone 1	2.0	West but low density strip
	3	North to South	West	A	East
Moombah	1	West to East	North	16.5	South
	2	West to East	North	11.5	South
	3	East to West	South	16.7	North

Table 3.1.2. Description of pasture transect distances for each zone and edge of tree strip used to convert distances to multiples of tree height. The two heights given for Moombah represent the height of the two distinct woody components, namely mature Poplar Box and shrub understorey.

Site	Tree height (m)	Transect Description						Transect Distances (metres)		
		Zone 1	Zone 2	Zone 3	Zone 4	Zone 5	Zone 6	Middle of Zone 2	Edge of strip Zone 1-2	Edge of strip Zone 2-3
Duke's Plain	6.5	0.00 – 9.0m	12 – 27m	27.5 – 33.5m	34 40.5m	41.5 – 55.5m	57.5 – 87.5m	19.5	9	27.5
Mt Lonsdale	18	4.0 – 15.5m *Road next to strip*	24.5 – 69.5m	70.0 – 77.5m	78.5 – 101.5m	103.5 – 149.5m	157.5 – 209.5m	47.0	15.5	70.0
Moombah	8-12 or 20	0.0 – 19.5m	34.5 – 109.5m	110.0 – 119.5m	120.0 – 150.5m	154.5 – 208.5m	218.5 – 308.5m	72.0	19.5	110.0

Table 3.1.3. Assessment of tree strip foliage projected cover and tree basal area. Note A: The values at Mt Lonsdale are not presented and are being reassessed to account for sampling anomalies.

Duke's Plain	REP1	REP2	REP3	Average	Standard Deviation
Green leaf	33	30	24	29	4.6
Green stem	24	23	19	22	2.6
Dead leaf	0	0	0	0	0.0
Dead stem	2	2	2	2	0.0
No vegetation	41	45	55	47	7.2
Total	100	100	100		
Tree Basal Area (m^2/ha)	10.8	20.6	13.6	15.0	5.0

Mt Lonsdale	REP1	REP2	REP3	Average	Standard Deviation
Green leaf	30	13	38	27.0	12.8
Green stem	5	3	9	5.7	3.1
Dead leaf	0	0	0	0.0	0.0
Dead stem	8	0	0	2.7	4.6
No vegetation	57	84	53	64.7	16.9
Total	100	100	100		
Tree Basal Area (m^2/ha)	A	A	A	A	A

Moombah	REP1	REP2	REP3	Average	Standard Deviation
Green leaf	21	35	26	27.3	7.1
Green stem	16	11	4	10.3	6.0
Dead leaf	2	0	1	1.0	1.0
Dead stem	4	4	2	3.3	1.2
No vegetation	57	50	67	58.0	8.5
Total	100	100	100		
Tree Basal Area (m^2/ha)	16.5	11.5	16.7	14.9	2.9

Table 3.1.4. Tree strip attributes and pasture transect harvest dates.

Site	Tree height (m)	Average tree basal area m^2/ha	Reset and harvest dates (2004)	Reset and harvest dates (2005)
Duke's Plain	6.5	15.0	Reset 22 July 2003 Harvest 12-16 May 2004	Reset 7 July 2004 Harvest 9-11 May 2005
Mt Lonsdale	18	17.5	Reset 2 September 2003 Harvest 24-30 May 2004	Reset 16 June 2004 Harvest 11-14 May 2005
Moombah	8 – 12 or 20	14.9	Not sampled	Reset 23 June 2004 Harvest 5-19 May 2005

Table 3.1.5. Distance of Zones from edge of tree strip expressed in terms of metres along the transect and multiples of tree height.

Location	Zone	Tree Height (m)	Edge of Tree Strip (m)	Minimum Edge of Zone (m)	Maximum Edge of Zone (m)	Average Distance of zone (m)	Minimum Edge of Zone (x tree height)	Maximum Edge of Zone (x tree height)	Average Distance of Zone (x tree height)
Duke's Plain									
Duk	1	6.5	9.0	0.5	9.0	4.75	1.31	0.0	0.65
Duk	2	6.5	0.0	12.0	27.0	19.5	0.0	0.0	0.0
Duk	3	6.5	27.5	27.5	33.5	30.5	0.0	0.92	0.46
Duk	4	6.5	27.5	34.0	40.0	37.0	1.0	1.92	1.46
Duk	5	6.5	27.5	41.0	55.0	48.0	2.08	4.23	3.15
Duk	6	6.5	27.5	57.0	87.0	72.0	4.54	9.15	6.85
Mt Lonsdale									
Mtl	1	18	15.5	4.0	15.5	9.75	0.64	0.0	0.32
Mtl	2	18	0.0	24.5	69.5	47.0	0.0	0.0	0.0
Mtl	3	18	70.0	70.0	77.5	73.75	0.0	0.42	0.21
Mtl	4	18	70.0	78.5	101.5	90.0	0.47	1.75	1.11
Mtl	5	18	70.0	103.5	149.5	126.5	1.86	4.42	3.14
Mtl	6	18	70.0	157.5	209.5	183.5	4.86	7.75	6.31
Moombah (tree height = 12m)									
Moo	1	12	19.5	0.0	19.5	9.75	1.63	0.0	0.81
Moo	2	12	0.0	34.5	109.5	72.0	0.0	0.0	0.0
Moo	3	12	110.0	110.0	119.5	114.75	0.0	0.79	0.4
Moo	4	12	110.0	120.5	150.5	135.5	0.88	3.38	2.13
Moo	5	12	110.0	154.5	208.5	181.5	3.71	8.21	5.96
Moo	6	12	110.0	218.5	308.5	263.5	9.04	16.54	12.79
Moombah (tree height = 20m)									
Moo	1	20	19.5	0	19.5	9.75	0.98	0	0.49
Moo	2	20	0	34.5	109.5	72	0	0	0
Moo	3	20	110	110	119.5	114.75	0	0.47	0.24
Moo	4	20	110	120.5	150.5	135.5	0.52	2.03	1.27
Moo	5	20	110	154.5	208.5	181.5	2.22	4.93	3.58
Moo	6	20	110	218.5	308.5	263.5	5.43	9.93	7.68

The different attributes of the tree strips are summarised in Table 3.1.6.

Table 3.1.6. Summary of tree strip attributes. Width is given as the distance between first sampling in Zone 3 and last sampling point in Zone 1 and hence represents the tree strip and associated features (i.e. road at Mt Lonsdale).

	Orientation	**Tree strip width, height**	**Woody vegetation type**	**Dominant grass species in the open pasture**
Duke's Plain	South West to North East	Width 18m Height 6.5m	Brigalow	Gayndah and Biloela buffel grass, Queensland bluegrass
Mt Lonsdale	North to South (Rep 1 and Rep 3)	Width 54m Height 18m	Poplar Box	Pitted bluegrass, Queensland bluegrass, wiregrasses and kangaroo grass
Moombah	West to East	Width 90m Height 12 or 20m	Mature Poplar Box and Shrub Understorey, e.g. Wilga	Biloela buffel grass

In the following analysis of the pasture transects (Section 4.2) and subsequent empirical model development (Section 4.5), the measurements of pasture standing dry matter are analysed in terms of distance from the tree strip. The implication of this approach is that the tree strip itself is the source of the effects represented in terms of microclimate (Section 4.1), competition for soil water (Section 4.4) and nutrients (Section 4.3), and soil nutrients and condition (Section 4.3). However, other factors affecting pasture growth could be correlated with distance from the tree strip such as soil disturbance and/or gradients in soil attributes. For example, the mechanics of tree clearing and regrowth control can result in systematic soil disturbance and accumulation of clearing debris (windrows), and ash bed parallel to the tree strip (e.g. Moombah).

Existing variation in the soil surface can influence water distribution. In the case of Mt Lonsdale, observations indicated surface undulations associated with linear gilgais. The possible effect of these small but systematic undulations is that runoff could move from areas of low cover and accumulate as run-on in systematic patterns (Section 4.4) nearly parallel to tree strips. Similarly, at Duke's Plain, one replicate (#1) had a gully through the tree strip affecting Zone 3. In this preliminary study, the objective is to quantify pasture growth and other factors associated with tree strips. At this stage of research, it is not possible to quantify the possible effects of other sources of variability as discussed above.

Rainfall and climate during experimental period

Tables 3.1.7 and 3.1.8 show rainfall for the experimental period at the three field locations, and at relevant rainfall recording stations reporting to the Bureau of Meteorology. Rainfall during the summer growing seasons (1 Nov to 30 Apr) was highly variable across southern Queensland for 2003/04 and 2004/05 (Plate 3.1.4). Thus, broadscale sources of year-to-year variation (e.g. 2004 El Niño) had variable impacts across locations in terms of relative rainfall (Table 3.1.7). The ranking of the years based on long-term reporting stations does not necessarily account for the differences that can occur due to spatial variability. Nevertheless, based on long-term rainfall records for the Bureau of Meteorology reporting stations, rainfall was within plus or minus 20% of average rainfall.

Table 3.1.7. Monthly rainfall (mm) for years of field experimentation at the three locations as well as relevant meteorological stations reporting to the Bureau of Meteorology.

Year	Month	Duke's Plain	Theodore	Mt Lonsdale	Mungallala	Moombah	St George
2003	Jan	35	17	26	32		4
2003	Feb	174	209	106	75		47
2003	Mar	51	61	72	67		38
2003	Apr	71	18	20	17		31
2003	May	4	5	39	8		11
2003	Jun	8	38	54	40		67
2003	Jul	29	12	30	30		38
2003	Aug	55	50	27	29		34
2003	Sep	4	1	0	0		0
2003	Oct	53	49	45	62		48
2003	Nov	7	30	43	68		7
2003	Dec	105	151	34	34		107
2004	Jan	128	96	186	238	102	118
2004	Feb	98	93	85	66	87	25
2004	Mar	40	33	55	63	88	54
2004	Apr	6	18	50	54	47	29
2004	May	0	0	10	6	0	5
2004	Jun	0	2	6	9	4	1
2004	Jul	5	0	5	6	12	9
2004	Aug	1	0	3	13	8	18
2004	Sep	37	33	37	29	58	42
2004	Oct	20	54	2	22	27	22
2004	Nov	112	146	57	77	71	91
2004	Dec	186	117	145	204	106	157
2005	Jan	32	49	16	21	123	31
2005	Feb	56	73	17	21	3	32
2005	Mar	54	49	26	42	21	10
2005	Apr	12	24	0	0	0	0
2005	May	66	56		115	97	77
2005	Jun	70	122		87	112	92
2005	Jul	0	0		0	0	3
2005	Aug	11	13		3	8	9
2005	Sep	6	10		10	14	14
2005	Oct	137	145		26	92	74

For the summer growing season rainfall (1 Nov to 30 Apr), rainfall at Duke's Plain was below average compared to Theodore for both years. Mt Lonsdale had contrasting years in terms of above-average (2003/04) and well below average (2004/05) compared to Mungallala. Moombah was close to the long-term average for St George.

Across the three locations and for both years, average annual maximum temperatures were greater than the long term average. For minimum temperature, 2004 was above average whilst 2005 was below average across the locations. In terms of pasture growth, the calculated temperature index for pasture growth ranged from 4 to 9% above average across locations and years. Similarly vapour pressure deficit (VPD), which affects plant water-use efficiency, was 5 to 16% above average reflecting the above average maximum temperatures in 2004 and 2005. Estimated Class A pan evaporation (Rayner *et al.* 2005) was 4 to 11% above average. Thus, in terms of plant growth, the warmer temperatures 2004 and 2005 could be regarded as more favourable than average, but other variables such as VPD and pan evaporation suggest below average conditions in terms of plant water use efficiency.

Table 3.1.8. Rainfall for years of field experimentation. The periods are the 12 months (1 May to 30 Apr) and the main summer growing season (1 Nov to 30 Apr). Values for homestead and relevant station reporting to the Bureau of Meteorology are shown.

Location	Year	Rainfall (mm) at Homestead	Rainfall Reporting Station	Year	Rainfall (mm)	Long Term Mean	% Deviation from long-term mean	Decile Range
1 May to 30 Apr								
Duke's Plain	2004 2005	538 514	Theodore	2004 2005	575 547	678 678	-15 -19	30-40 20-30
Mt Lonsdale	2004 2005	648 324	Mungallala	2004 2005	691 450	509 509	+36 -12	80-90 40-50
Moombah	2005	430	St George	2005	417	511	-18	30-40
Summer 1 Nov to 30 Apr								
Duke's Plain	2004 2005	386 451	Theodore	2004 2005	421 458	464 464	-9 -1	30-40 Median
Mt Lonsdale	2004 2005	453 261	Mungallala	2004 2005	523 365	340 340	+54 +7	80-90 60-70
Moombah	2005	323	St George	2005	320	316	+1	50-60

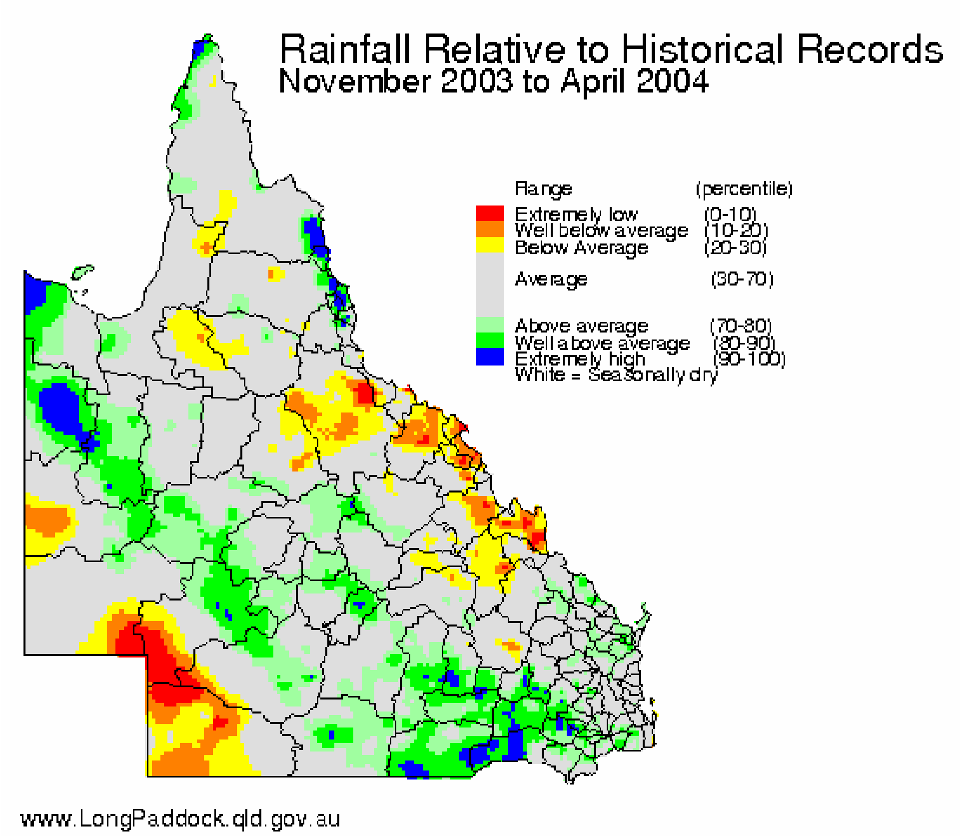


Plate 4.1.1. Rainfall relative to historical records for the summer of 2003/04.

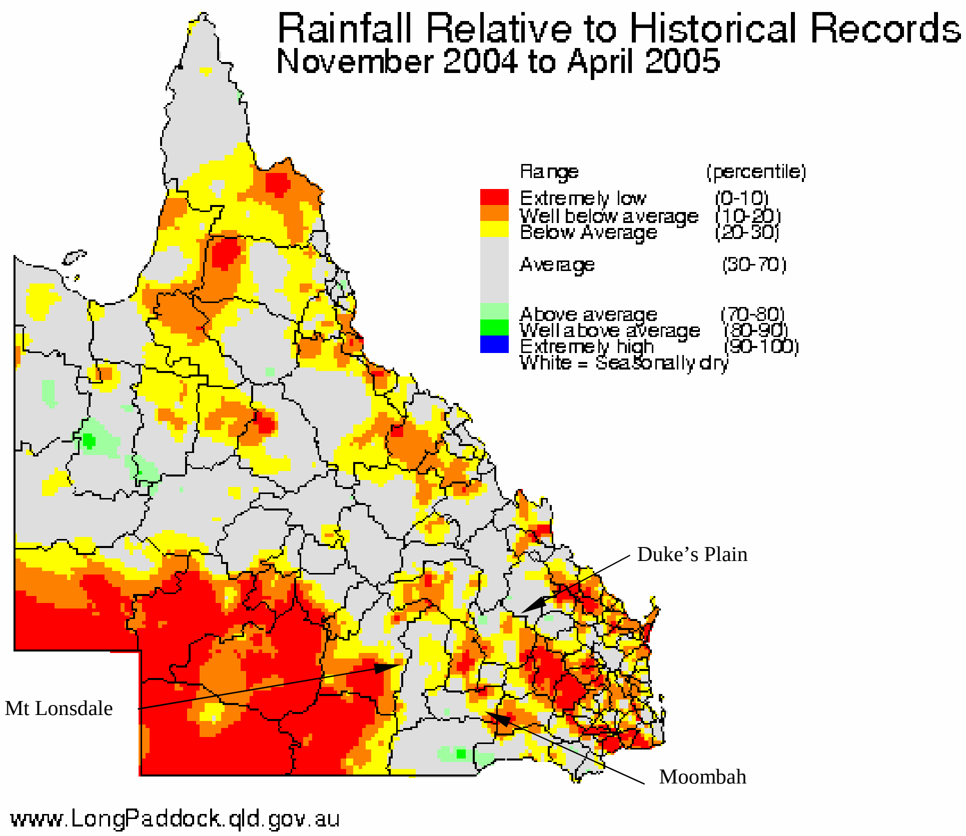


Plate 4.1.2. Rainfall relative to historical records for the summer of 2004/05.

4 Results and Discussion

4.1 Microclimate effects of tree strips

4.1.1 Introduction

Tree strips are known to influence pasture microclimate through several processes (e.g. Cleugh 2003):

1) direct interception of rainfall and solar radiation by the tree canopy;
2) changes in light quality (e.g. increased diffuse radiation);
3) shading of adjacent zones (i.e. Zones 1 and 3 in this study) particularly in the morning and afternoon;
4) changes in wind speed with consequent changes in air temperature and potential evapo-transpiration, both within the tree strip and at distances several multiples of tree height away from the strip;
5) frost and night-time cooling; and
6) changes in relative humidity or vapour pressure deficit both under the tree canopy and across the transect as a result of shading, wind and temperature.

Thus, the influence of tree strips is complex in terms of the interactions of climate variables affecting pasture growth and landscape topography.

The tree strips studied in this project have different locations, orientation within a paddock, widths, tree densities and foliage cover (Section 3.1). Because of the expense involved in terms of equipment and maintenance, it was not possible to measure all climate variables across all transects. The approach adopted was to concentrate on measuring key attributes at contrasting locations and strip/transect orientations within a paddock. These data will support the later development of microclimate models and hence provide a more comprehensive analysis of pasture microclimate across the range of possible combinations of tree strip variables.

Table 4.1.1. Distance (metres) of meteorological station for measurements of climate variables along pasture transects. The middle of Zone 2 has been calculated from the position of transect measurements in Zones 1 and 3 at the edge of the tree strip.

Duke's Plain

Zone	Distance from middle of Zone 2	Distance on Transect	Zone width on Transect	Distance from edge of strip	Multiple of tree height (6.5m)
Zone 1	-13	5.3	0 – 9[A]	-3.8	-0.58
Zone 2	0	18.3	12 – 27	-9.3	
Zone 3	13	31.3	27.5[B] – 33.5	3.8	0.58
Zone 4	19	37.3	34 – 40.5	9.8	1.50
Zone 5	34	52.3	41.5 – 55.5	24.8	3.81
Zone 6	60	78.3	57 – 87.5	50.8	7.81

Mt Lonsdale

Zone	Distance from middle of Zone 2	Distance on Transect	Zone width on Transect	Distance from edge of strip	Multiple of tree height (18m)
Zone 1	-32	10.8	4 – 15.5[A]	-4.8	-0.26
Zone 2	0	42.8	24 – 69.5	-27.3	
Zone 3	32	74.8	70[B] – 77.5	4.8	0.26
Zone 4	48	90.8	78.5 – 101.5	20.8	1.15
Zone 5	88	130.8	103.5 – 149.5	60.8	3.38
Zone 6	164	206.8	157.5 – 209.5	136.8	7.60

Moombah

Zone	Distance from middle of Zone 2	Distance on Transect	Zone width on Transect	Distance from edge of strip	Multiple of tree height (12 & 20m)
Zone 1	-50	14.8	0 – 19.5[A]	-4.8	-0.40 -0.24
Zone 2	0	64.8	34.5 – 109.5	-45.3	
Zone 3	50	114.8	110[B] – 119.5	4.8	0.40 0.24
Zone 4	70	134.8	120 – 150.5	24.8	2.06 1.24
Zone 5	120	184.8	154.5 – 208.5	74.8	6.23 3.74
Zone 6	240	304.8	218.5 – 308.5	194.8	16.23 9.74

[A] Edge of strip adjacent to Zone 1
[B] Edge of strip adjacent to Zone 3
[C] Distance from edge of main transect (B)

4.1.2 Methods

4.1.2.1 Layout

Meteorological stations were placed in all 6 zones in one replicate at each of the three sites (Table 4.1.1). The stations recorded temperature (at 30 cm), relative humidity, wind speed (converted to daily wind run) and solar radiation, as well as a wind vane logging wind direction at one station per site. Solar radiation sensors were placed only in Zone 2 (underneath trees) and Zone 6 (open) at Moombah. The distance of the stations from the tree strip varied with the sites (see above). In addition a set of 12 stations were placed at all zones across the remaining two replicates (per site) for shorter periods of time in order to have some replication in the measurements. For detailed layout see Figures 4.1.1 to 4.1.3.

4.1.2.2 Wind speed and direction

Wind speed

Wind speed was measured at 5 zones in one replicate at Duke's Plain during 2004. In addition a wind vane logging direction of wind was located at zone 6 on all of the sites but did not provide useful data. Wind speed was measured using 014A Met One Wind Speed Sensors. Output from the instruments was logged using either Campbell Scientific 10X loggers or Tinytag loggers. All sensors were located approximately 150cm above ground level. Output from the sensors was given in metres per second as a 60 minute average. Daily wind run was calculated.

Although wind instruments were installed at Mt Lonsdale and Moombah, there were insufficient resources to regularly maintain and monitor the equipment. It is recommended, based on this experience that these types of measurements should not be attempted unless there are adequate resources for regular travel involving considerable distances to widely spaced locations. A more central location for managing the project would have facilitated easier access to the locations.

Wind direction

Wind direction was not measured at the field sites. Hence, wind direction data were evaluated for relevant meteorological stations operated by the Bureau of Meteorology (Plate 4.1.1). For Duke's Plain, data were available from Taroom and Brigalow Research Station. For Mt Lonsdale, data were available from Charleville and Roma. For Moombah, data were available from St George. The detailed analysis of these data is presented in Appendix 10.11.

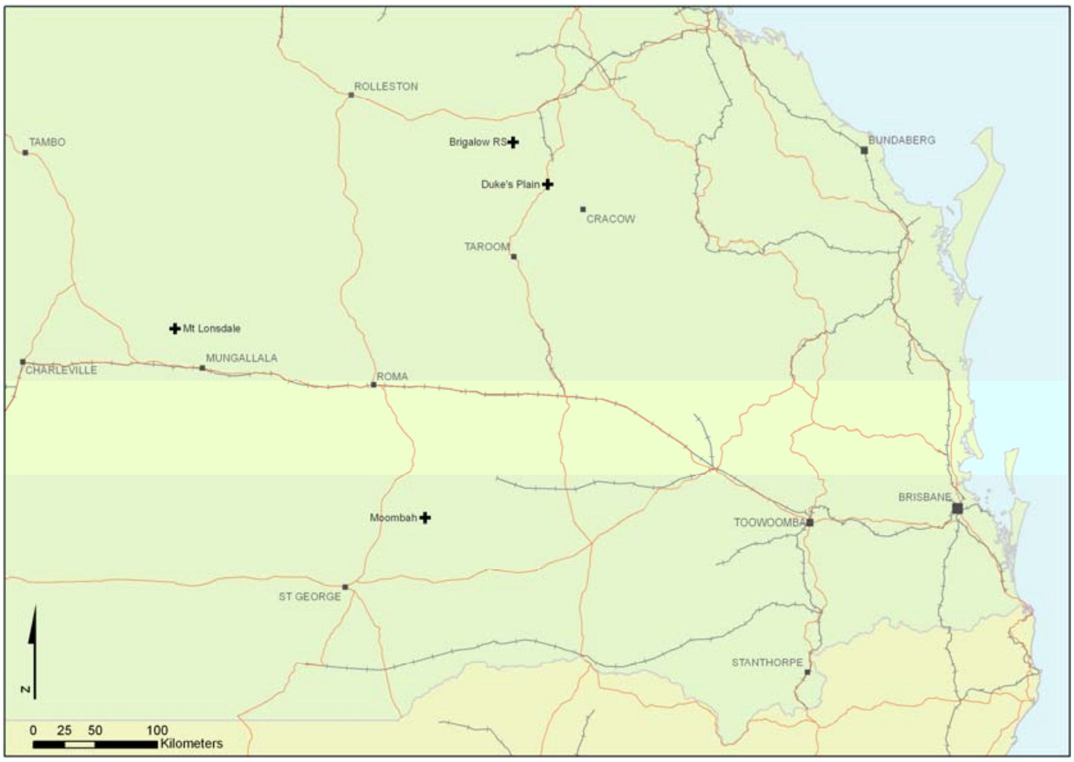


Plate 4.1.1. The location of Meteorological Stations used to analyse wind direction data in relation to the field sites.

4.1.2.3 Temperature and relative humidity

Temperature was measured using a combination of Campbell Scientific CS 500 Temperature and relative humidity probes (housed in a radiation shield), and Gemini Data Loggers (Tinytag). Temperature and relative humidity sensors were housed in shaded and ventilated screens. All loggers were located approx 30 centimetres above ground level. The CS500 Temperature and relative humidity sensor contains a platinum Resistance Temperature detector and a Vaisasa INTERCAP® capacitive relative humidity sensor. (Campbell Scientific 2004, 1) and has an operating range of -40ºC to + 60ºC.

Table 4.1.2. Period of temperature measurement at each location. At Duke's Plain, consistent measurement at Zones 1 to 4 occurred from 3 Jan 2004 to 29 Sep 2004. Humidity was also measured at Mt Lonsdale and Moombah (Appendix 10.8).

Location	Start of temperature measurement	End of temperature measurement	Number of days
Duke's Plain	24 Oct 2003	7 May 2005	Various
Duke's Plain	3 Jan 2004	29 Sep 2004	229
Mt Lonsdale Rep 2	29 Jan 2005	9 Nov 2005	287
Mt Lonsdale Rep 3	23 Feb 2005	9 Nov 2005	260
Moombah Rep 2	23 Jun 2004	6 Dec 2004	167
Moombah Rep 3	22 Jun 2004	22 Feb 2005	246

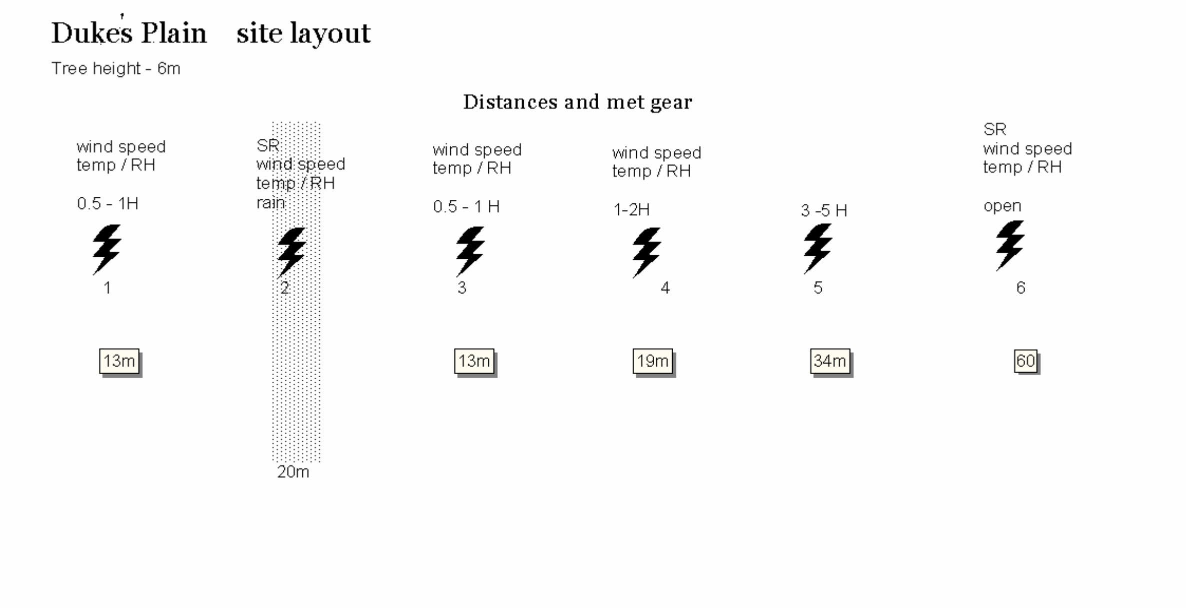


Figure 4.1.1. Layout of microclimate stations at Duke's Plain.

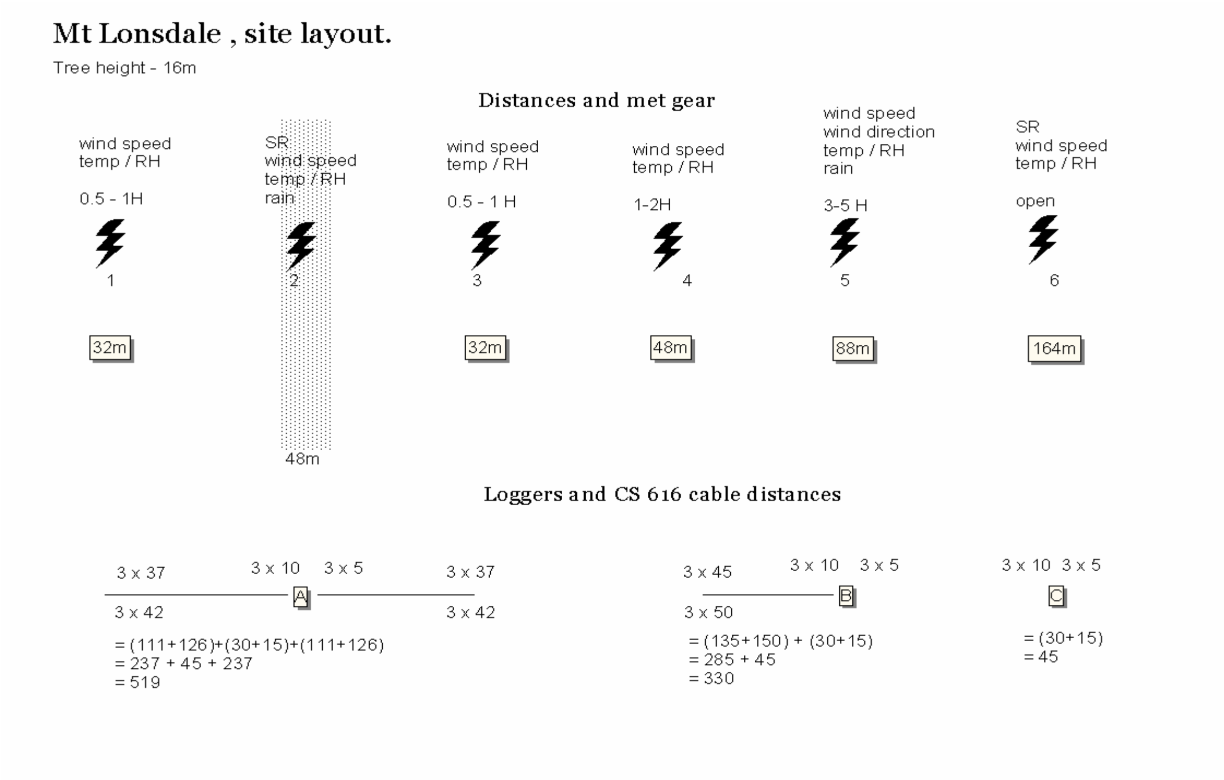


Figure 4.1.2. Layout of microclimate stations at Mt Lonsdale.

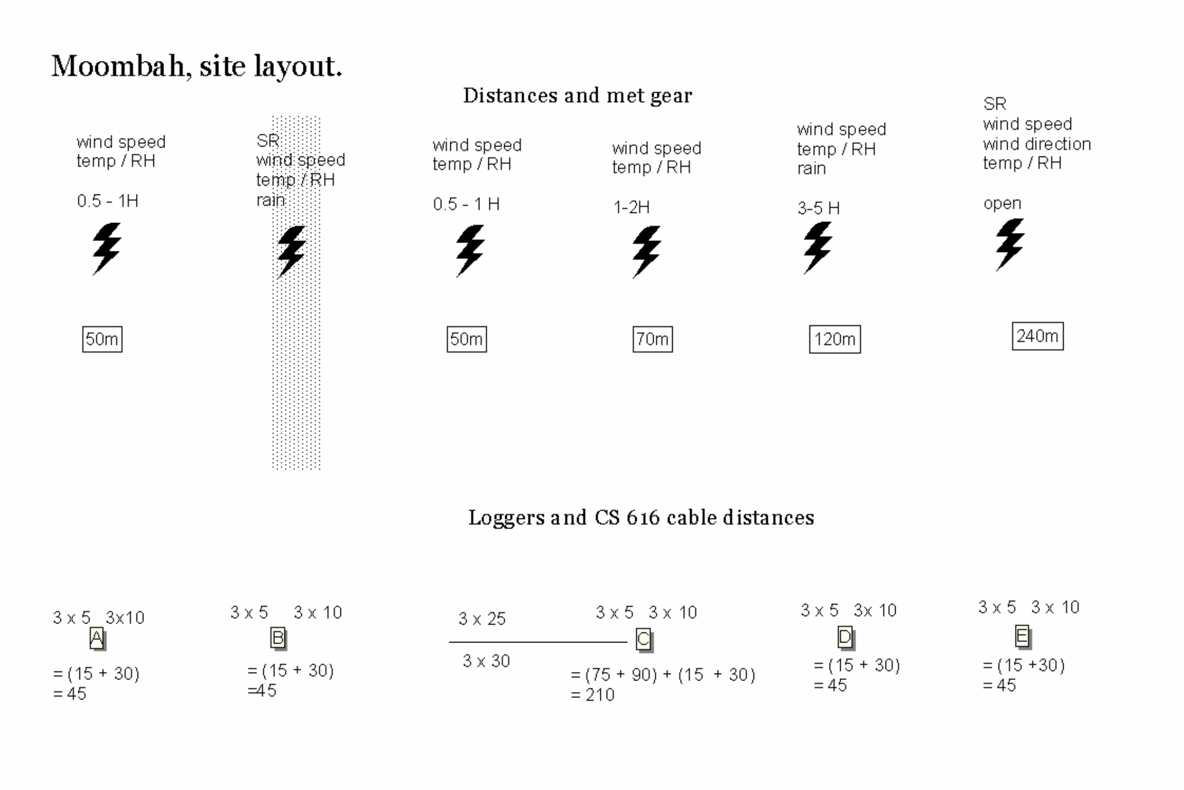


Figure 4.1.3. Layout of microclimate stations at Moombah.

4.1.3 Results

Given the possible influence of tree strips on wind, a major deficiency in climate data is the lack of historical data on wind run or direction for the region. Further analyses of climate data will be required to place the experimental period in an historical context with regard to these important variables.

Daily wind run

During 2004, daily wind run was measured at Duke's Plain at Zones 1-6 (with exception of Zone 5). It was not possible to obtain continuous measurements at each zone although measurements span the seasonal (winter to summer) range of values. Figure 4.1.4 shows the time series of measurements for each zone and Figure 4.1.5 compares each zone with Zone 6 (open pasture furthest from tree strip). Table 4.1.2 shows regressions between Zone 6 with other zones. Strong correlations occurred only between Zone 6 and Zone 2 (inside tree strip). Based on a regression through the origin, Zone 1 (0.58 tree height south east of tree strip) had 40% more wind than Zone 6 (8 x tree heights) on the other side of the tree strip. In contrast, Zones 2 and 3 had 19% and 36% reduction in daily wind compared to Zone 6. Zone 4 had higher wind than Zone 6 (+15%) although measurements suggest possible instrumental error (Figure 4.1.4). The measurements suggest the tree strip has a large effect on daily wind run given the (perceived) prevailing south-easterly wind direction at this location. Thus the orientation of the tree strip provided some protection for the downwind side. The measurements also show the difficulty of measuring daily wind run under field conditions at remote locations.

High values were measured at Zone 1 and Zone 4 and these are yet to be confirmed with comparison with nearest meteorological station measuring wind. The results highlight the complexity of the role of tree strips influencing wind (and evaporative demand) environment at each zone. Because of the difficulty of measurement, wind measurements were not successful at the other locations.

Table 4.1.3. Regression between daily wind run at Zone 6 and daily wind run at Zones 1 to 4 at Duke's Plain. Site orientation is given in Figure 3.1.2 and Table 3.1.1. Zone 1 is south east of the tree strip. These results are provisional as daily wind run data are yet to be validated.

Zone Distance	Distance from middle of tree strip (m)	Regression	R^2	N	Regression through Origin	Distance from edge of tree strip in tree height multiples
Zone 1	13	91.4 + 0.818x	0.186	121	1.396	0.59
Zone 2	0	11.6 + 0.732x	0.740	161	0.813	-
Zone 3	13	54.6 + 0.242x	0.105	165	0.636	0.58
Zone 4	19	94.8 + 0.468x	0.132	180	1.115	1.50

Analysis of wind direction from relevant meteorological stations

Wind direction is an important meteorological variable in terms of orientation of tree strips. However, wind direction was not measured at the field sites during the experimental period. Hence we have adopted the following approach to analyse wind direction data from relevant meteorological stations:

1) Meteorological stations located in southern Queensland were evaluated in terms of the availability of observations of wind direction.
2) Climatological analyses (long-term records) in the form of wind roses from the Bureau of Meteorology were examined and examples presented (Figure 4.1.6).
3) Daily data for the recent period (2003 to 2008) including the years of field experimentation were obtained from the Bureau of Meteorology.
4) Data were examined in terms of wind direction from the 16 compass points for different times of the day 0900, 1200, 1500 hours (hr).
5) Data were averaged for each quadrant (NE, SE, SW, NW).
6) Following Cleugh (2003), wind directions relevant to the orientation of the tree strips were evaluated.
7) The wind directions were aggregated in terms of frequency of days with wind direction parallel, perpendicular or at 45 degrees to the orientation of the tree strips.
8) The data were summarised in terms of parallel, perpendicular and 45 degrees for the summer period for both experimental years 2004 and 2005.

The following preliminary analysis of wind direction does not include wind speed or the temperature and humidities that would be associated with different directions. In general, it would be expected that north-westerly winds were associated with hotter drier conditions while south-westerly winds would be colder and drier. North-easterly winds are likely to have a higher humidity content while south-easterlies are likely to be stronger. A more detailed analysis of data for each location is required to test these generalities.

The effects of tree strips on pasture microclimate have different implications for different seasons and times of year. For example, tropical pasture growth occurs mainly during the warm growing season (summer). The diurnal variation in vapour pressure deficit and evaporative demand are likely to have larger effects on tropical grass growth (e.g. Seneweera *et al.* 1998), and hence in the following analysis of wind direction, we concentrate on the daytime period, i.e. 0900, 1200 and 1500 hours (hr).

Figure 4.1.6 indicates the wind roses for Taroom (relevant to Duke's Plain), Charleville (relevant to Mt Lonsdale) and St George (relevant to Moombah) for January and August and 0900hr and 1500hr. Taroom was the closest meteorological station with observations throughout the day. A more relevant station is Brigalow Research Station, but observations are only available for 0900hr (Plate 4.1.1). The results from Brigalow Research Station are discussed in later sections. Values have been calculated by the Bureau of Meteorology from observations collected for over 40 years up to 2004. At Taroom in January, winds are mainly from the north-east at 0900hr but at 1500hr they are mainly from the south-east. In contrast in August, wind is mainly from the south-west at 0900hr and 1500hr. At Charleville in January, wind direction was mainly from the north at 0900hr but was from mainly from the south-east quadrant at 1500hr. In August, wind was still mainly from the north and east at 0900hr but was mainly from the west and the south at 1500. At St George, wind was mainly from the north or north-east at 0900 in January whilst at 1500hr it ranged from the north-east to the south-west. In August, wind directions were from the south or south-west for both 0900hr and 1500hr.

Thus from a climatological viewpoint (i.e. long-term averages) the dominant wind directions in January at 1500 for the 3 sites varied– south-easterlies at Taroom, northerlies at St George and variable but mainly south-easterly at Charleville.

Analysis of year-to-year variation in wind direction

A more detailed analysis of wind direction was carried out using daily wind direction data from the Bureau of Meteorology from 2002 to 2008 for a range of locations and different seasons – summer (1 October to 31 March) and winter (1 April to 30 September). Locations included Taroom and Brigalow Research Station (relevant to Duke's Plain), Charleville and Roma (relevant to Mt Lonsdale) and St George (relevant to Moombah). Wind direction (16 compass points) was available for 0900 for all locations, 1200hr for 3 locations and 1500hr for four locations (Appendix 10.11). The percentage of days was calculated for the four quadrants of wind direction (NE, SE, SW, NW). An example for 0900hr is given in Table 4.1.4. Other times are given in Appendix 10.11. Directions relevant (i.e. perpendicular and parallel to tree strip) to the site orientation were also calculated (Table 4.1.5). For 0900hr, data were also available from Brigalow Research Station near Theodore.

Both Brigalow and Taroom indicate the dominance of wind direction from the north-east quadrant, however, at Brigalow there was some year-to-year variation in the dominant direction and there was a stronger percentage of south-easterlies compared to Taroom. At 1500hr, wind directions are mainly from the north-east and south-east with variation between years. For the two years of the experiment (2004 and 2005) there was a dominance of both north-east and south-east winds with the summer of 2004.

At Charleville and Roma at 0900hr, there was a clear dominance of north-easterlies. There was less year-to-year variation at Roma. Data were also available for 1200hr and showed a similar dominance of north-easterlies. However at Charleville, there was a substantial percentage of days with wind from the north-west (19-38% of days) with 37% of days during the dry summer of 2005 i.e. 1 October 2004 to 31 March 2005. For 1500hr, there was a greater range of wind directions with variation between years as to the dominant quadrant.

At St George at 0900hr, wind directions were mainly from the north-east quadrant. Similarly at 1200hr they were mainly from the north-east but with a substantial percentage of days 16 – 25% from the north-west. At 1500hr, there was dominance of winds from the south-east quadrat except in 2005. For the year of experimental data (2005), wind was mainly from the south-west quadrant (38%).

In winter at 0900hr, wind direction at Brigalow was mainly from the south-east but at Taroom it was mainly from the south-west. At Charleville, Roma and St George wind was mainly from the north-east. At Charleville, Roma and St George at 1200hr wind direction was quite variable with all quadrants being represented. For all locations at 1500hr, wind direction was mainly from the south-east or south-west quadrants. There was substantial variability between years in terms of the dominance of particular quadrant directions.

Wind direction in terms of tree strip orientation

Cleugh (2003, p.58) states "while windbreaks are most effective when the wind blows perpendicular to them, they continue to give good levels of shelter even if the wind shifts to around 30 degrees to the perpendicular, provided the windbreak is sufficiently long. Then, as the angle grows further, the sheltered area declines at an increasingly rapid rate".

The components of wind direction were calculated for the years 2004 and 2005 for the directions that are perpendicular and parallel to the tree strips most relevant to each location. Percentage days were calculated for wind direction from the three compass points closest to tree strip orientation (i.e. $\pm$ 22.5 degrees, Appendix 10.11).

Duke's Plain
At Duke's Plain, the tree strips ran from north-east to south-west and hence wind directions from the south-east and the north-west would be perpendicular to the tree strip. At Brigalow in the summer of 2004 (i.e. 1st October 2003 to 31st March 2004), wind direction at 0900hr was mostly northerly or south-easterly whilst 2005 was highly variable in direction. The frequency of winds parallel to the tree strips (18-21% north easterlies and south-westerlies) was less than frequency of winds perpendicular to the strips (34-37%) in both years. At Taroom, the percentage of days with wind parallel to the tree strips was similar to the percentage of days with wind perpendicular to the tree strips (about 40%). For 1500hr, there was a high percentage of days with south-easterlies in 2004 but a higher proportion of north-easterlies in 2005. The frequency of parallel and perpendicular winds were similar in 2004 whilst there were more parallel winds in 2005.

Mt Lonsdale
At Mt Lonsdale, the tree strips ran north-south and hence east-west winds would be perpendicular to the tree strip. In summer at Charleville and Roma for 0900hr, the majority of days had wind from the north (43-56%) and there was little difference between the two years 2004 and 2005. The frequency of parallel winds (51-64%) greatly exceeding the frequency or perpendicular winds (19-24%). At 1500hr, there was similar percentage of days (≈30-40%) with parallel and perpendicular directions to the tree strips. In the drought year of 2005, there were more parallel than perpendicular winds at Charleville and Roma (41, 39% compared to 33, 28% respectively).

Moombah
At Moombah, the tree strips were east-west in orientation and hence winds from the north or south are perpendicular to the tree strip. In the 2005 summer at St George at 0900hr, northerlies were the dominant wind (43%) with a further 18% of days with winds from the south. Thus, perpendicular (northerlies and southerlies) winds had a substantially higher frequency (61%) than parallel winds (16%). Similarly at 1200hr and at 1500hr there also was a higher percentage of days with perpendicular winds (e.g. 51-50%) than parallel (e.g. 27-29%) respectively.

Summary of perpendicular and parallel wind direction frequencies.
The analysis of wind direction for the years of field study suggests that, in the case of Moombah, there was a high frequency of summer winds from directions perpendicular to the tree strip orientation at the relevant meteorological station St George (Table 4.1.5). Thus, the tree strip would be expected to reduce wind speed in the pasture interspace. For Mt Lonsdale, the relevant locations were Charleville and Roma which had similar patterns of diurnal and year-to-year variation at 0900, 1200 and 1500hr. At 0900hr, parallel winds were at a higher frequency, whilst at 1500hr the frequencies of parallel and perpendicular winds were similar. At Duke's Plain, the two available meteorological stations Taroom and Brigalow Research Station, had different frequencies of directions at 0900hr. The results from Brigalow, the closer station was more consistent with the expectation of a greater frequency of perpendicular winds, particularly south-easterlies as suggested by the measurement of wind run (Table 4.1.2 and Figure 4.1.4).

From consideration of frequency of wind direction, the effects of tree strips on pasture micro-climate would be expected to be greatest at Moombah and Duke's Plain and less at Mt Lonsdale. With regard to Mt Lonsdale, the grazier co-operator Bill Douglas regarded the north/south orientation of the tree strips as a suitable direction to reduce the impact of westerly and prevailing south-easterly winds (e.g. Charleville, Figure 4.1.6b). However, the analysis of summer wind direction for the experimental period (2004/05) for Charleville and Roma airports suggest that parallel winds were more likely to have occurred. As well as variation between years, local effects such as topography and fragmented areas of vegetation cover could also influence prevailing wind direction at particular sites. Further research will be required to estimate the effects of tree strips at specific sites.

Given that there is considerable variation in terms of wind direction and speed through the day and between seasons and years, more sophisticated models will be required to integrate the effects of tree strips on pasture microclimate. We regard this more detailed analysis as important in terms of providing input to the pasture growth model GRASP described in Chapter 4.7. The pasture growth model GRASP has a daily timestep and hence daily values would be required by integrating the diurnal distribution of wind speed, vapour pressure deficit and evaporative demand.

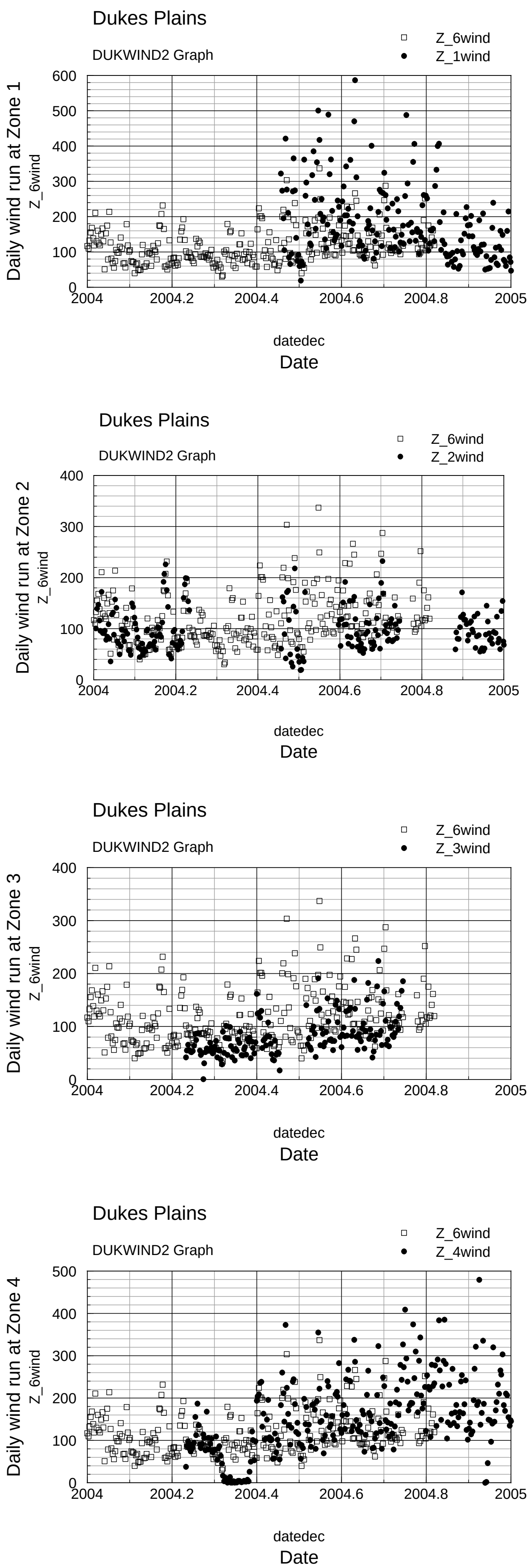


Figure 4.1.4. Daily wind run at Duke's Plain for Zones 1-6. Zone 1 was on the south-east side of the tree strip with orientation south-west to north-east. Zone 1 was 0.6 x tree height, Zone 2 was in the middle of the tree strip, Zone 3 was 0.6 x tree height, Zone 4 was 1.5 x tree height, and Zone 6 was 8 x tree height. For Zone 4, values less than 30km/day have not been included in the analysis (Table 4.1.2).

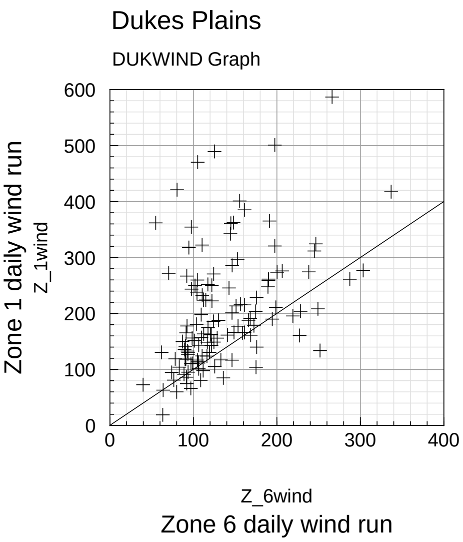


Figure 4.1.5a. Comparison of daily wind run measured at Zone 1 and Zone 6 at Duke's Plain. The tree strip is orientated from south-west to north-east. Zone 1 was on the south-east, 4 metres (0.6 x tree height) from the edge of the strip.

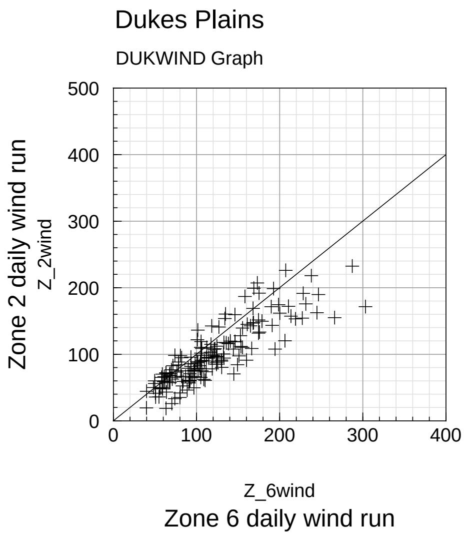


Figure 4.1.5b. Comparison of daily wind run measured at Zone 2 and Zone 6 at Duke's Plain. The tree strip is orientated from south-west to north-east. Zone 2 was in the middle of the tree strip, 9 metres from the edge of the tree strip.

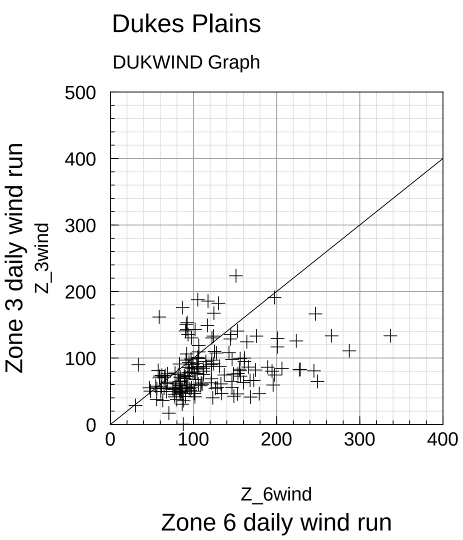


Figure 4.1.5c. Comparison of daily wind run measured at Zone 3 and Zone 6at Duke's Plain. The tree strip is orientated from south-west to north-east. Zone 3 was 4 metres (0.6 x tree height) north-west of the edge of the tree strip.

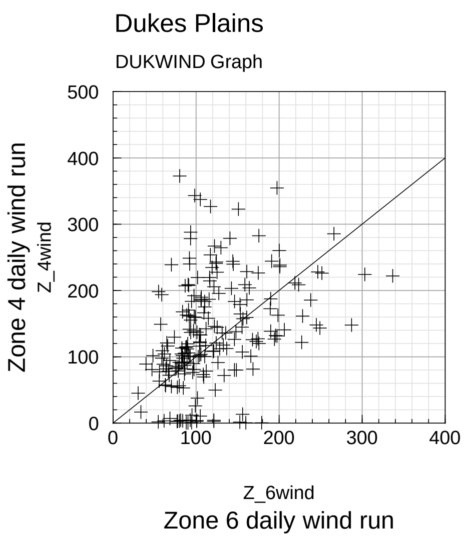
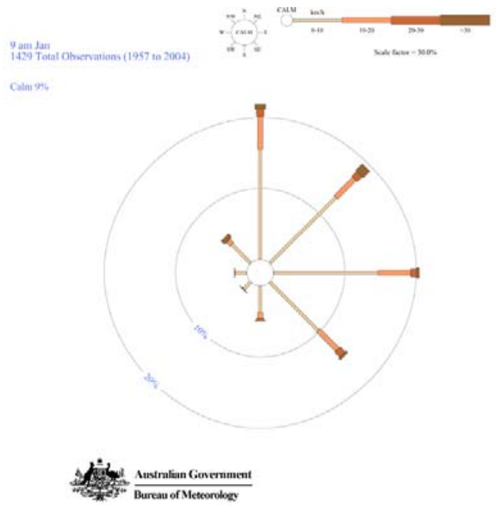
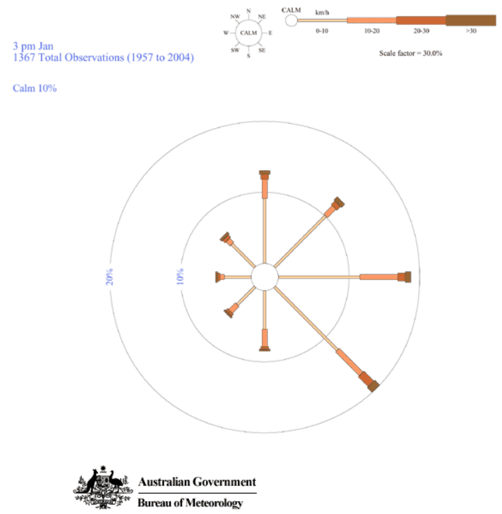


Figure 4.1.5d. Comparison of daily wind run measured at Zone 4 and Zone 6 at Duke's Plain. The tree strip is orientated from south-west to north-east. Zone 4 was 10 metres (1.5 x tree height) north-west of the edge of the tree strip.



a)



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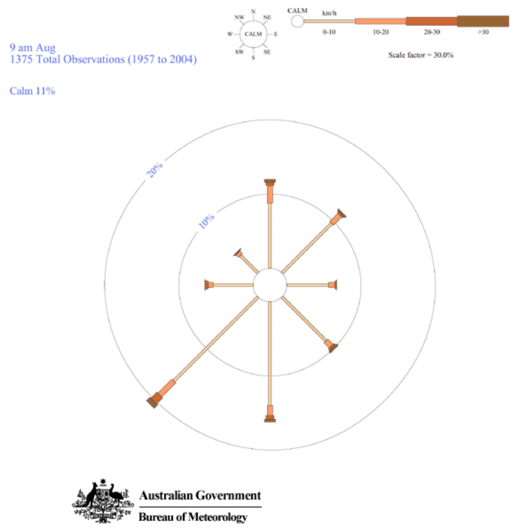

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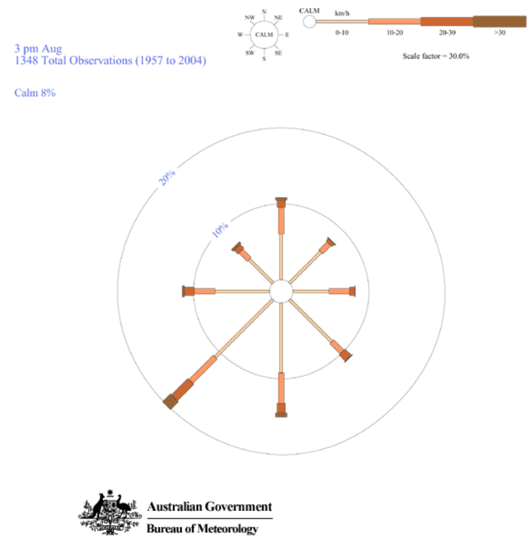
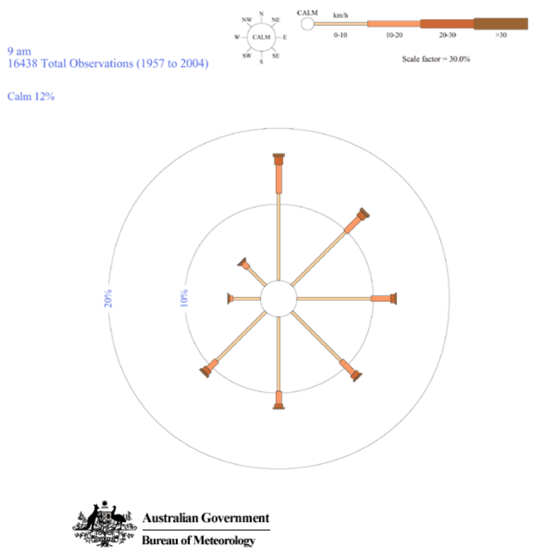


d)

Figure 4.1.6a. Wind roses for Taroom based on data collected from 1957 to 2004. Data presented for (a) 9.00am January; (b) 3.00pm January; (c) 9.00am August; (d) 3.00pm August; and (e) 9.00am annual.



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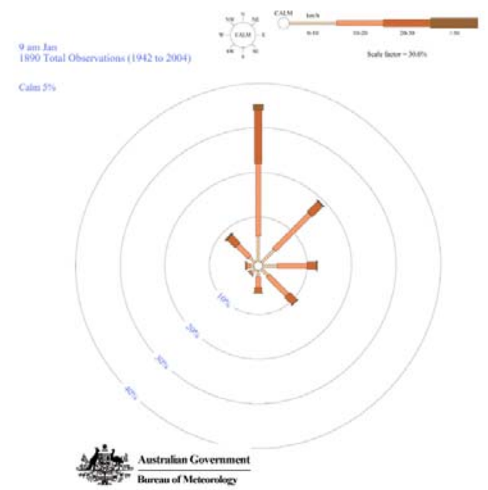

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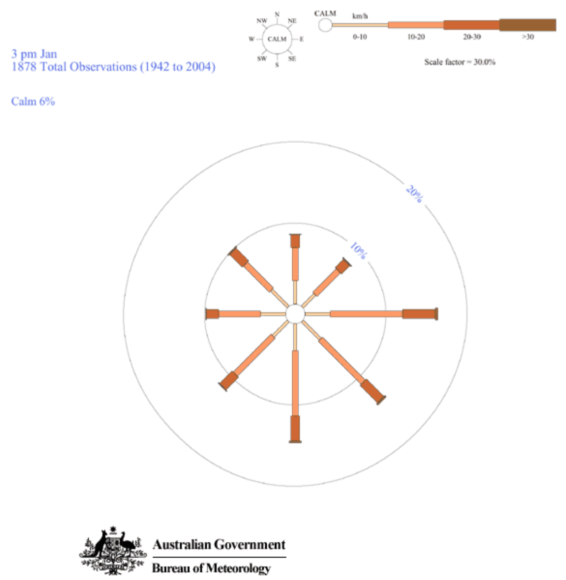

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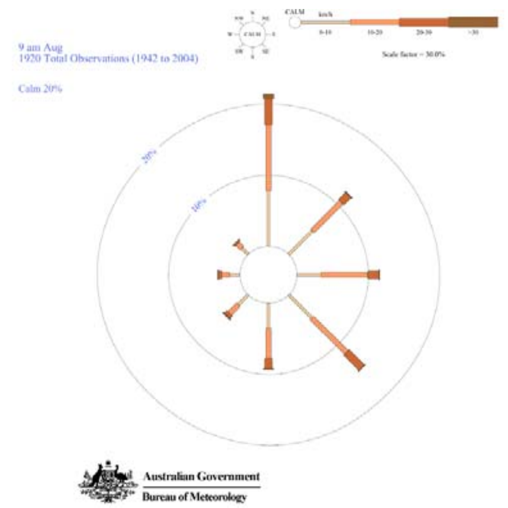

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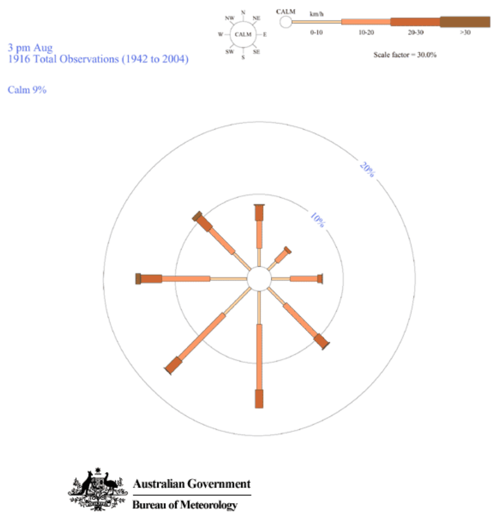
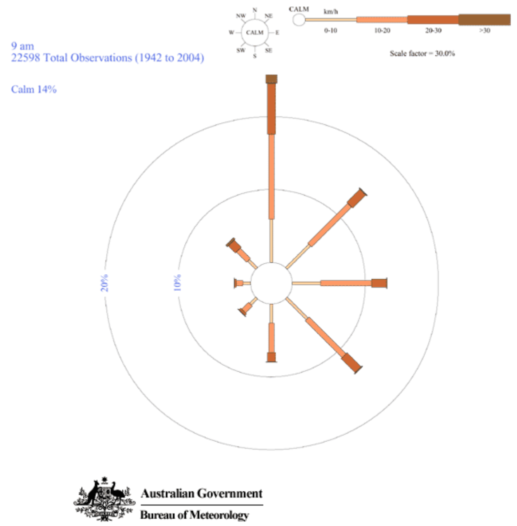


d)

Figure 4.1.6b. Wind roses for Charleville based on data collected from 1942 to 2004. Data presented for (a) 9.00am January; (b) 3.00pm January; (c) 9.00am August; (d) 3.00pm August; and (e) 9.00am annual.



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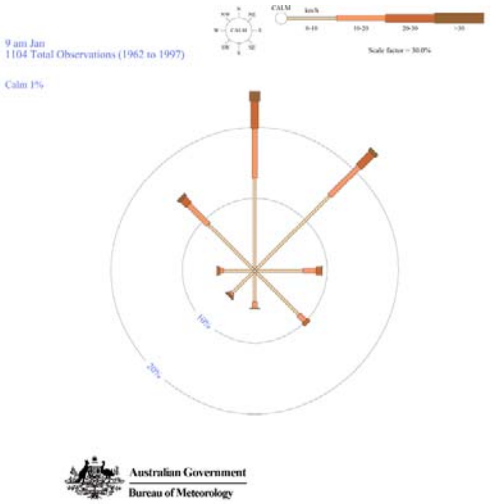
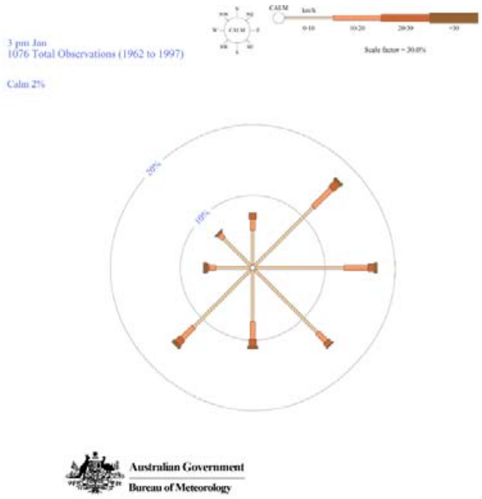


a)



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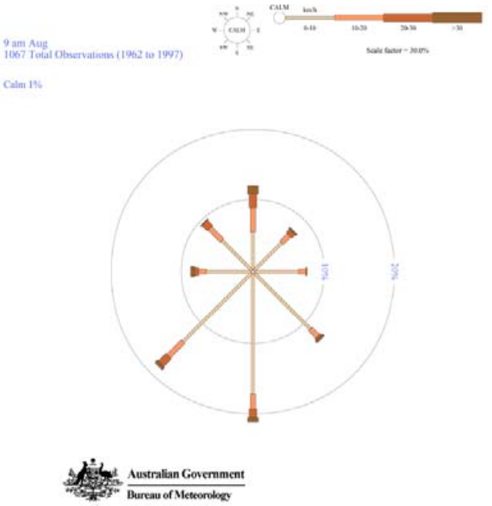

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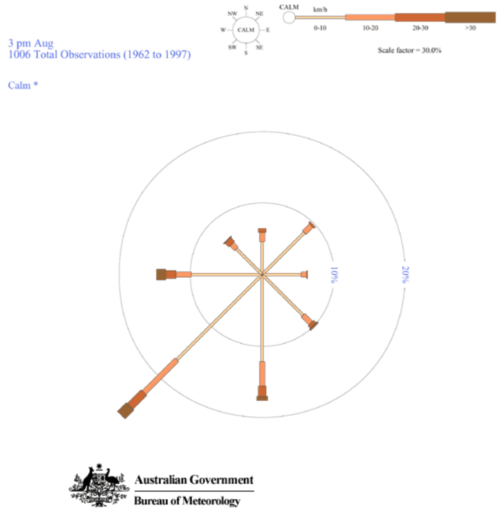
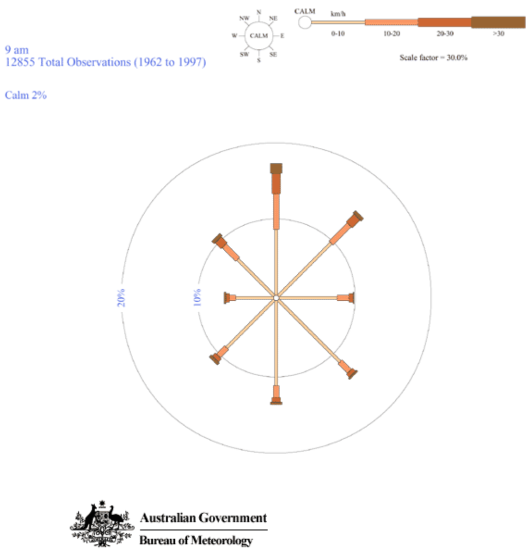


d)

Figure 4.1.6c. Wind roses for St George based on data collected from 1962 to 1997. Data presented for (a) 9.00am January; (b) 3.00pm January; (c) 9.00am August; (d) 3.00pm August; and (e) 9.00am annual.



e)

Table 4.1.4. Percentage of days at locations in southern Queensland with wind direction from different quadrants for 0900 hours. North-east (north to east-north-east); south-east (east to south-south-east); south-west (south to west-south-west); north-west (west to north-north-west). The summer season is from the 1 October to 31 March and winter from the 1 April to 30 September. The year is given for the end of summer or the end of winter.

Season	Location	Year	North- East	South-East	South-West	North-West	Calm+
Summer	Brigalow	2003	44	45	7	1	3
		2004	46	35	7	10	3
		2005	30	28	9	24	8
		2006	37	30	5	24	4
		2007	30	43	5	18	3
		2008	18	60	6	12	3
Summer	Taroom	2003	47	40	3	8	2
		2004	47	23	6	23	1
		2005	46	24	7	23	0
		2006	54	16	5	24	1
		2007	61	18	6	15	0
		2008	42	38	5	15	0
Summer	Charleville	2003	67	27	3	3	0
		2004	53	22	7	18	0
		2005	47	31	4	18	0
		2006	57	20	7	16	0
		2007	65	19	4	12	1
		2008	59	25	6	10	0
Summer	Roma	2003	67	24	3	4	1
		2004	65	15	7	13	0
		2005	63	16	11	11	0
		2006	69	14	4	10	2

Season	Location	Year	North- East	South-East	South-West	North-West	Calm+
		2007	80	10	5	6	0
		2008	57	26	7	9	1
Summer	St George	2003	60	22	10	7	1
		2004	53	15	12	14	6
		2005	54	21	14	11	1
		2006	60	18	8	14	0
		2007	66	13	10	10	0
		2008	62	15	9	5	9
Winter	Brigalow	2003	28	43	24	2	4
		2004	12	42	20	14	12
		2005	14	52	18	7	9
		2006	14	44	28	11	3
		2007	13	43	19	16	9
Winter	Taroom	2003	30	22	35	11	2
		2004	23	19	35	22	2
		2005	22	26	32	18	2
		2006	19	28	33	19	1
		2007	24	25	30	20	1
Winter	Charleville	2003	47	33	8	8	3
		2004	45	32	8	10	5
		2005	56	25	6	8	5
		2006	37	43	8	8	5
		2007	42	35	13	9	2
Winter	Roma	2003	43	19	21	9	7

Season	Location	Year	North- East	South-East	South-West	North-West	Calm+
		2004	45	9	26	11	9
		2005	45	18	15	13	9
		2006	37	21	27	5	9
		2007	42	19	24	10	6
Winter	St George	2003	38	24	21	15	2
		2004	46	14	27	10	3
		2005	53	16	17	13	2
		2006	36	33	18	10	3
		2007	32	22	24	20	2

Table 4.1.5. Percentage of days at locations in southern Queensland with wind direction from parallel and perpendicular directions compared to relevant sites for summer. The summer season is from the 1 October to 31 March and winter from the 1 April to 30 September. The year is given for the end of summer or the end of winter.

Location	Year	Time	Parallel	Perpendicular	Winds at 45^o	Calm
Duke's Plain			**NE + SW**	**SE + NW**		
Brigalow	2004	0900	21	34	42	3
Brigalow	2005	0900	19	37	35	8
Taroom	2004	0900	39	40	20	1
	2005	0900	42	33	25	0
	2004	1500	37	40	24	0
	2005	1500	43	30	27	1
Mt Lonsdale			**N + S**	**E + W**		
Charleville	2004	0900	64	21	15	0
	2005	0900	59	23	19	0
Roma	2004	0900	51	19	30	0
	2005	0900	55	24	21	0
Charleville	2004	1200	42	31	27	0
	2005	1200	45	31	24	0
Roma	2004	1200	34	42	24	0
	2005	1200	44	28	28	0
Charleville	2004	1500	36	36	27	1
	2005	1500	41	33	26	0
Roma	2004	1500	33	37	29	0
	2005	1500	39	28	33	0
Moombah			**E + W**	**N + S**		
St George	2005	0900	16	61	22	1
	2005	1200	27	51	21	1
	2005	1500	29	50	21	0

Temperature

Daily temperatures (minimum, maximum and average) were measured at the three locations. In the case of Mt Lonsdale and Moombah two replicate transects were used allowing comparison of the effects of tree strip density and tree strip orientation to be measured.

It is expected that effects on wind and maximum temperature are correlated (Cleugh and Hughes 2002, p690). For example, reduced wind speed would be expected to be correlated with increased temperature. The temperature measurements at Duke's Plain will allow a more detailed daily comparison of temperature and daily wind effects once the wind data have been validated. For all sites, comparison between Zone 6 (open pasture) and other zones were made (Appendix 10.8).

Duke's Plain
Figures 4.1.7, 4.1.8 and 4.1.9 show the comparisons for Duke's Plain for minimum, maximum and average temperature respectively where there was considerable variation across zones.

Overall results for Duke's Plain and the other four sites (2 locations by 2 Reps) are summarised in Tables 4.1.6 and 4.1.7. The comparisons for Mt Lonsdale and Moombah did not show the same degree of variability as Duke's Plain (Appendix 10.8). It is yet to be determined whether this is a feature of the different topography, closeness of tree strips or difference in instrumentation.

For the Duke's Plain data, temperature difference between zones showed high variability with the exception of the relationship between Zone 2 and Zone 6. Different approaches in data analysis were used to estimate the temperature differences between Zone 6 (open pasture, furthest distance from tree strip) and other zones (Table 4.1.6). Zone 2 (within the tree strip) had lower maximum temperatures (-0.53 to -0.69) and higher minimum temperatures (0.97 to 1.11) with the range depending on type of data analysis. Zones 1, 3 and 4 had substantially higher maximum temperatures than Zone 6: 1.09 to 2.05 depending on locations and method of analysis. The effects are consistent with reductions in wind speeds reported in the previous section (e.g. Cleugh 2003, page 25). Minimum temperatures were also higher in these zones. Thus, the tree strips at Duke's Plain had a substantial effect on temperature, particularly maximum temperature in zones close to the tree strip. It is important to note that Zone 6 (the furthest distance from the tree strip) was 8-10 x tree height from the tree strip and hence, was still in the zone where the effects of tree strips on pasture microclimate would be expected to occur (Cleugh 2003, page 24).

As yet daily wind run and temperature measurements at Duke's Plain have not been paired. Once regional daily wind surfaces have been calculated, the next important step is to calculate the daily impacts of tree strips on potential evaporative demand and atmospheric moisture stress on pastures. i.e. vapour pressure deficit (VPD).

Table 4.1.6. For Duke's Plain, comparison of temperature differences between Zone 6 (open pasture, greatest distance from tree strip) and other zones (e.g. Zone 2 is within tree strip). Different periods and data rejection rules were considered because of the high variability in the relationship between measurements at different zones (Figures 4.1.7, 4.1.8 and 4.1.9). Initially, because of limited availability, instruments were moved between zones, and hence the number of observations in each comparison varies. Values for the period when the four zones were instrumented (i.e. data from both Zone 2 and 6 present) are shown.

All data			Days with large differences between zones removed		Four zones measured (3 Jan to 29 Sep 2004)		Growing Season (3 Jan to 30 Apr 2004)	
Zone	**Difference**	**No. of Obs**	**Difference**	**No. of Obs**	**Difference**	**No. of Obs**	**Difference**	**No. of Obs**
Minimum								
1	0.46	361	0.41	338	0.43	229	0.47	117
2	1.06	242	1.11	229	1.11	229	0.97	115
3	0.72	360	0.66	337	0.71	228	0.55	117
4	0.32	361	0.27	338	0.24	228	0.16	117
Maximum								
1	1.21	361	1.25	338	1.26	229	1.36	117
2	-0.53	242	-0.69	229	-0.69	229	-0.37	115
3	1.74	360	1.76	337	1.84	228	2.05	117
4	1.22	361	1.23	338	1.29	228	1.09	117
Average								
1	0.53	360	0.53	337	0.49	228	0.63	117
2	0.23	242	0.18	229	0.18	229	0.25	115
3	0.81	360	0.81	337	0.86	228	0.84	117
4	0.50	361	0.5	338	0.50	228	0.41	117

Mt Lonsdale

The two replicates at Mt Lonsdale have substantially different tree strips with Rep2 having a much lower tree basal area and a parkland-like appearance in contrast to Rep3 (Tables 3.1.1, 3.1.3). The aspect of Zones 3 to 6 was also different with Rep2 having a western aspect and Rep3 having an eastern aspect. These differences in tree strip attributes and aspects are reflected in the comparisons between Zone 6 and other zones (Tables 4.1.7, Figures 4.1.10 and 4.1.11). For example for Rep3, minimum temperatures were on average 0.80°C warmer than Zone 6 compared smaller increases 0.16°C in the lower tree density Rep2. In the case of maximum temperature, Rep2 tree strip had little impact across zones. In contrast Rep3 (higher density, eastern aspect) there were lower temperatures in Zone 2 and Zone 3 (0.67, 0.49 lower than Zone 6). These effects were also reflected in average temperature. Thus the comparison of Reps2 and 3 showed that aspect, tree density and associated foliage cover have an expected effect on temperature. Importantly, the high density tree strip (Rep3) had reduced maximum temperatures (0.49) in Zone 3 (eastern side of strip) suggesting a more favourable environment in terms VPD. This effect was greater than on the western side (Zone 1) or in Rep2 with a lower tree density and western aspect.

The average effect on maximum temperature at Zone 4 in Rep 3 (0.21°C, Table 4.1.7) was small and lower than Duke's Plain (1.09-1.22°C). The lower maximum temperature measured in Zone 3 (≈5 metres from tree strip edge) at Rep 3 suggests the effect of shade in the afternoon (-0.49°C). In the case of Rep 2, which had a much lower tree density and a western aspect, there was little difference in maximum temperature along the pasture transect. Nevertheless, the effects of tree strips on funnelling parallel winds needs to be considered in interpretation of Zone 3 temperatures.

Moombah
The two climate transects measured at Moombah had contrasting orientations with Zones 3 to 6 being south of the tree strip in Rep2 and on the north side in Rep3. These different aspects were reflected in the comparison with Zone 6 in terms of maximum temperature (Table 4.1.7, Figures 4.1.10 and 4.1.11). The north aspect Rep3 had higher 'temperature' in Zone 3 and 4 than the equivalent zones in the southerly aspect of Rep2 ('Temperature' is expressed as the difference from Zone 6). Specifically, Zone 1 and 3 had the expected effects of aspect on shading for Reps 2 and 3 respectively. There were also some differences in minimum temperature which may reflect topographical effects on night time cooling.

In conclusion, the results for Mt Lonsdale and Moombah confirm the importance of orientation and aspect (exposure) in terms of the influence of tree strips on minimum and maximum temperature.

Humidity

Relative humidity was measured at Mt Lonsdale and Moombah. Preliminary analysis (Appendix 10.8) indicated intermittent periods of instrument failure. More detailed analysis of the data, in combination with temperature, will be required to determine the changes in humidity and vapour pressure deficit across the tree strip – pasture transect.

Conclusion

The effects of tree strips on temperature would be expected to be smaller if there was a greater frequency of winds blowing parallel to the tree strips. A more detailed analysis linking daily variation in wind direction and speed to temperature effects is yet to be done. Nevertheless, the strongest average effects on daytime maximum temperature were at Duke's Plain and Moombah. This finding was consistent with the low percentage of parallel wind directions measured at relevant meteorological stations (Brigalow Research Station and St George, Table 4.1.5). The smaller effect of tree strips on daytime maximum temperature at Mt Lonsdale, was consistent with the higher percentage of parallel winds measured at Charleville and Roma meteorological stations. However, as a caveat, we indicate that the field measurements of temperature at Mt Lonsdale were only for 2005 (a dry year) and further analysis of year-to-year variability in wind direction and temperature differences is still required.

The climate measurements taken in this study confirm that tree strips have an influence on microclimate of pastures across zones. As expected, orientation and tree density affect the degree of influence. This study also highlighted the difficulty of measuring the impact of tree strips on climate variables given the large number of climate variables that are likely to be affected (solar radiation, wind, temperature, humidity and potential evapo-transpiration). As detailed and comprehensive as the measurements taken in this study are, nevertheless there are insufficient climate data to construct daily climate files along a transect for each tree strip. Thus the assessment of tree influence in terms of impact on pasture microclimate described in Section 4.7 used the average effects derived from the above analysis.

Table 4.1.7. Comparison of minimum, maximum and average temperature measured along the pasture transect for Mt Lonsdale and Moombah. Temperature differences at Zones 1 to 5 with Zone 6 (furthest distance from tree strip) are shown. For Mt Lonsdale Rep2, Zones 3 to 6 are on the western side of the 'parkland' tree strip. For Mt Lonsdale Rep3, Zones 3 to 6 are on the eastern side of the dense tree strip. For Moombah Rep2, Zones 3 to 6 are on the southern side of the tree strip. For Moombah Rep3, Zones 3 to 6 are on the northern side of the tree strip. A = not measured.

Variable	Average Difference from Zone 6 Mt Lonsdale Temperature Rep2	Average Difference from Zone 6 Mt Lonsdale Temperature Rep3	Average Difference from Zone 6 Moombah Temperature Rep2	Average Difference from Zone 6 Moombah Temperature Rep3
Zone 1 minimum	A	0.49	0.32	0.42
Zone 2 minimum	0.16	0.80	0.95	0.83
Zone 3 minimum	0.30	0.59	0.68	0.02
Zone 4 minimum	0.19	0.31	0.25	0.03
Zone 5 minimum	-0.14	0.06	0.60	-0.17
Number of observations	285	260	167	246
Zone 1 maximum	A	0.02	1.01	0.84
Zone 2 maximum	0.05	-0.67	0.55	0.20
Zone 3 maximum	0.02	-0.49	0.58	1.14
Zone 4 maximum	-0.08	0.21	0.18	0.60
Zone 5 maximum	0.00	-0.01	-0.10	0.25
Number of observations	285	260	167	246
Zone 1 average	A	0.16	0.49	0.44
Zone 2 average	-0.02	0.16	0.32	0.29
Zone 3 average	0.13	0.20	0.50	0.26
Zone 4 average	0.01	0.17	0.15	0.16
Zone 5 average	-0.12	0.04	0.29	0.02
Number of observations	285	260	167	246

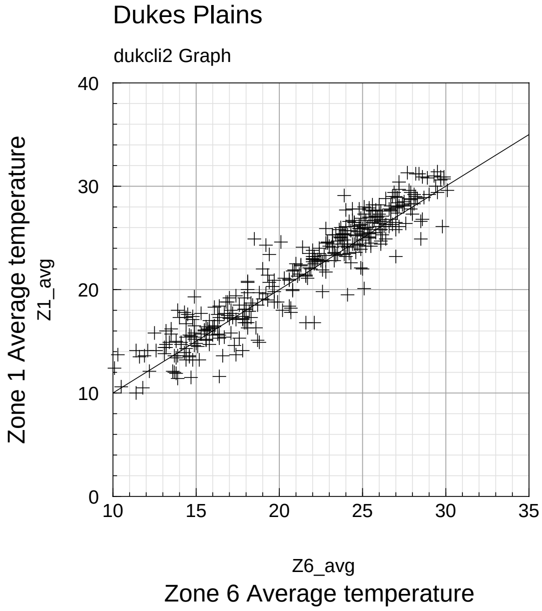


Figure 4.1.7a. The relationship between average temperature measured in Zone 6 compared to Zone 1 (immediately outside the canopy of the tree strip, but on the opposite side to Zone 6). The one-to-one line is indicated.

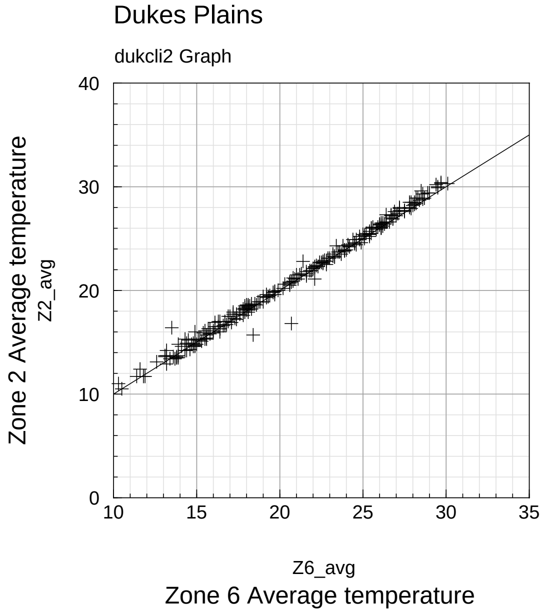


Figure 4.1.7b. The relationship between average temperature measured in Zone 6 compared to Zone 2 (inside the tree strip). The one-to-one line is indicated.

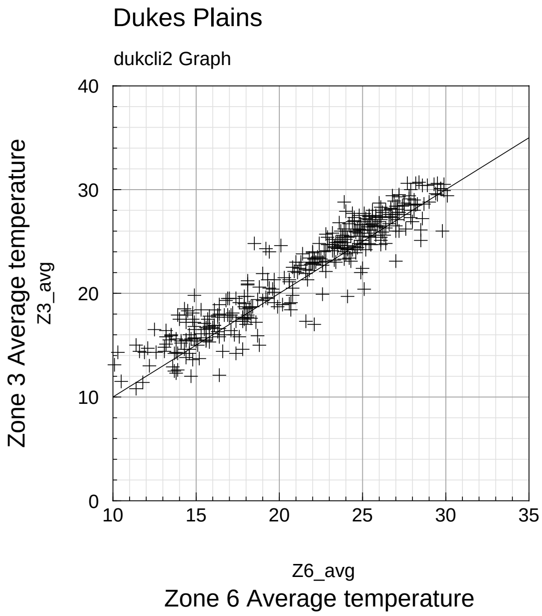


Figure 4.1.7c. The relationship between average temperature measured in Zone 6 compared to Zone 3 (immediately outside the canopy of the tree strip, but on the same side as Zone 6). The one-to-one line is indicated.

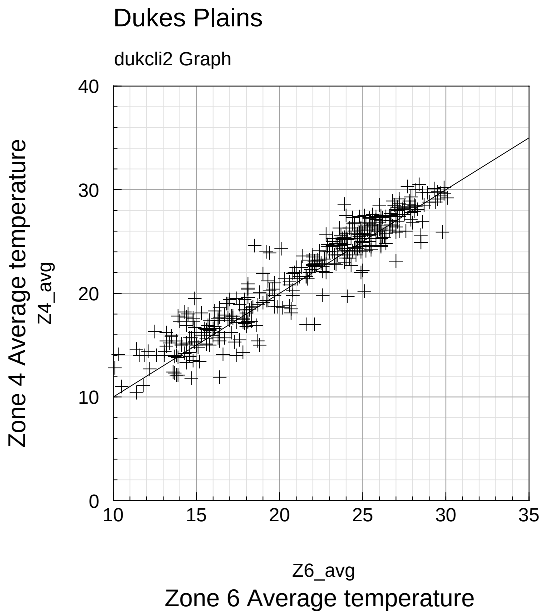


Figure 4.1.7d. The relationship between average temperature measured in Zone 6 compared to Zone 4 (1-2 times tree height from the tree strip, but on the same side as Zone 6). The one-to-one line is indicated.

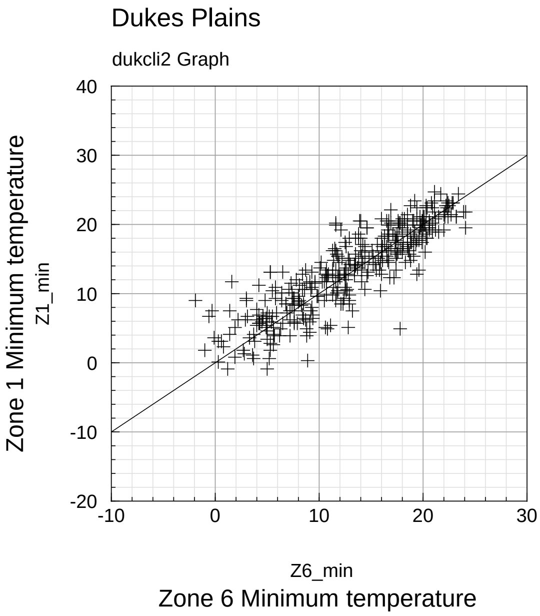


Figure 4.1.8a. The relationship between minimum temperature measured in Zone 6 compared to Zone 1 (immediately outside the canopy of the tree strip, but on the opposite side to Zone 6). The one-to-one line is indicated.

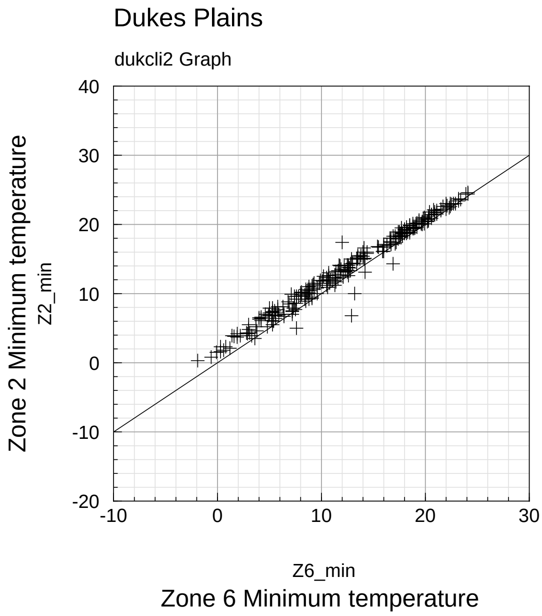


Figure 4.1.8b. The relationship between minimum temperature measured in Zone 6 compared to Zone 2 (inside the tree strip). The one-to-one line is indicated.

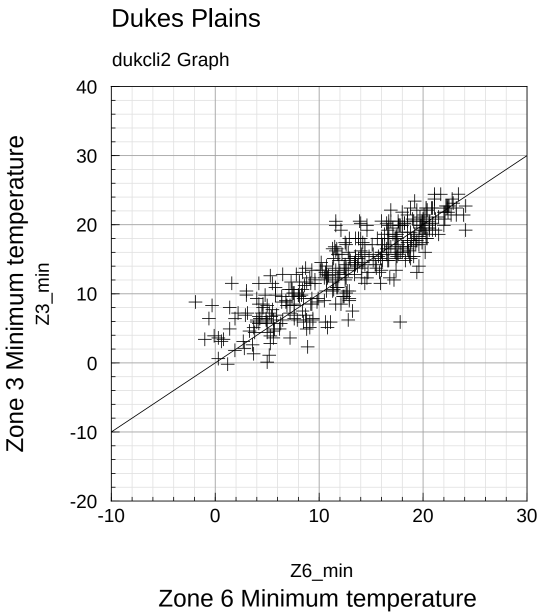


Figure 4.1.8c. The relationship between minimum temperature measured in Zone 6 compared to Zone 3 (immediately outside the canopy of the tree strip, but on the same side as Zone 6). The one-to-one line is indicated.

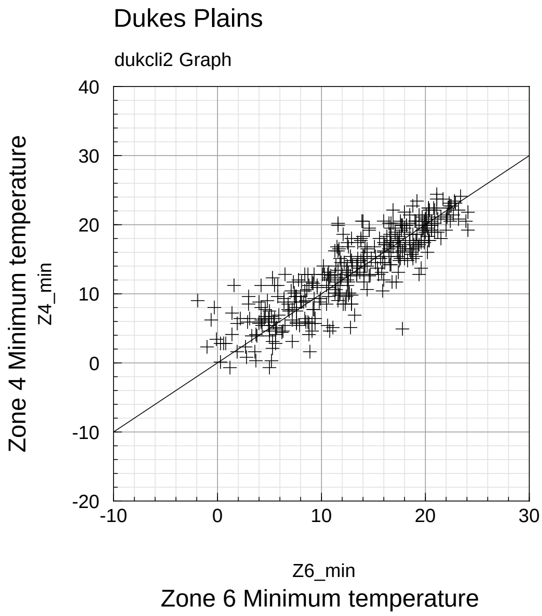


Figure 4.1.8d. The relationship between minimum temperature measured in Zone 6 compared to Zone 4 (1-2 times tree height from the tree strip, but on the same side as Zone 6). The one-to-one line is indicated.

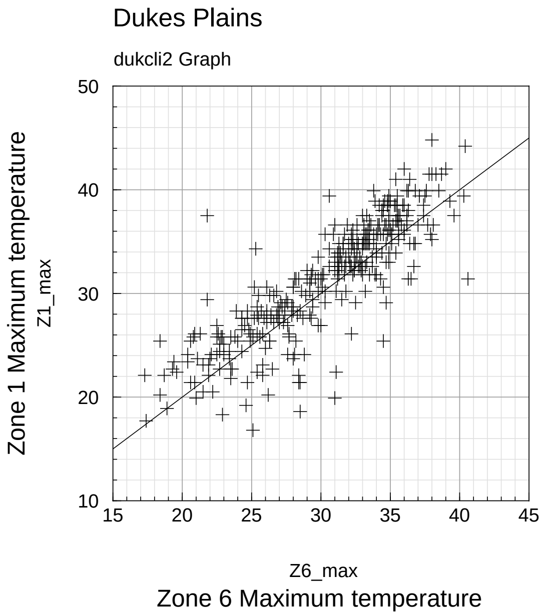


Figure 4.1.9a. The relationship between maximum temperature measured in Zone 6 compared to Zone 1 (immediately outside the canopy of the tree strip, but on the opposite side to Zone 6). The one-to-one line is indicated.

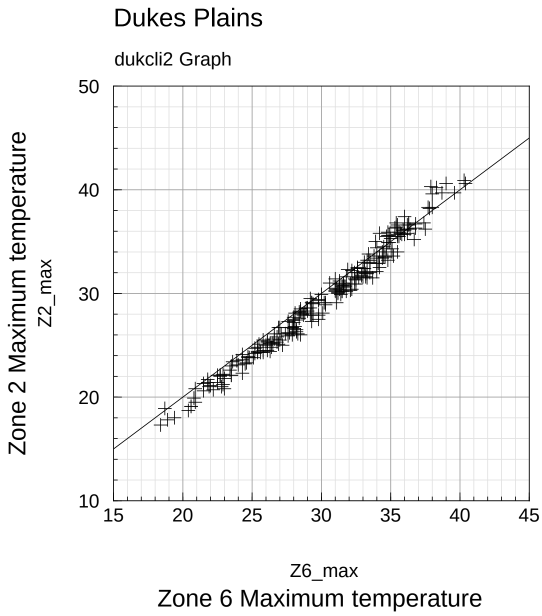


Figure 4.1.9b. The relationship between maximum temperature measured in Zone 6 compared to Zone 2 (inside the tree strip). The one-to-one line is indicated.

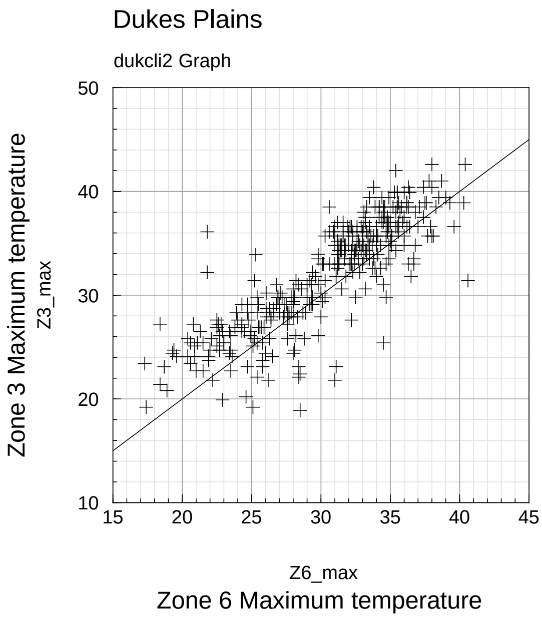


Figure 4.1.9c. The relationship between maximum temperature measured in Zone 6 compared to Zone 3 (immediately outside the canopy of the tree strip, but on the same side as Zone 6). The one-to-one line is indicated.

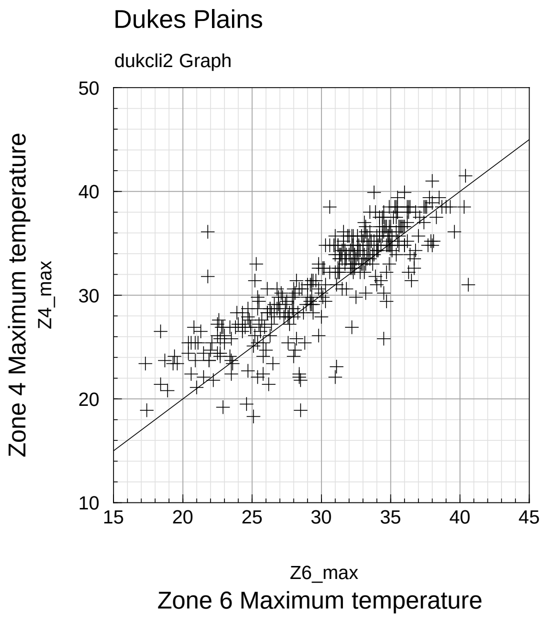
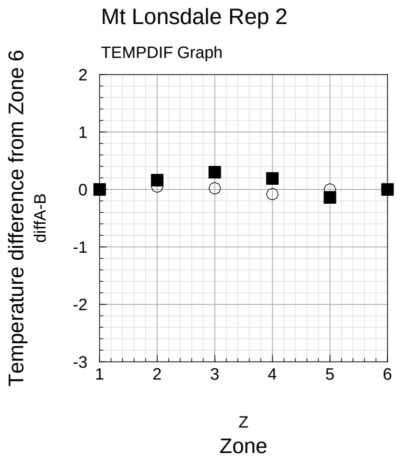
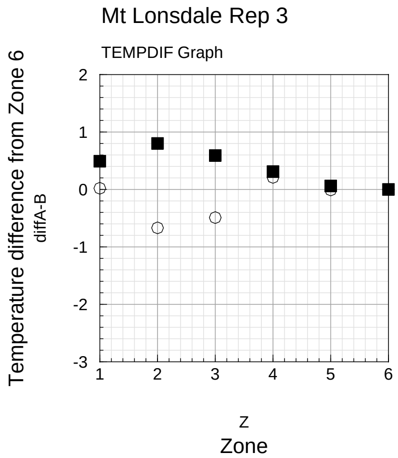
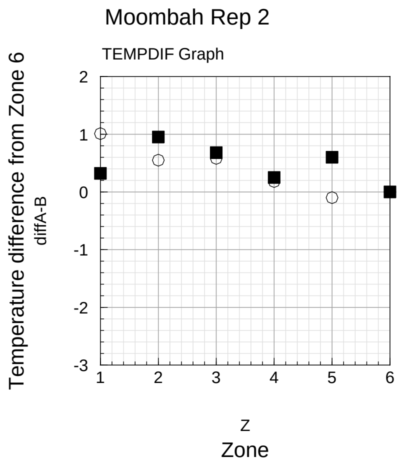
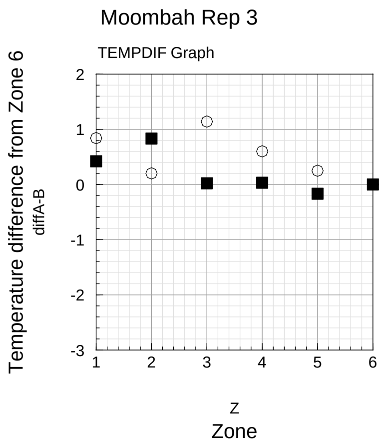


Figure 4.1.9d. The relationship between maximum temperature measured in Zone 6 compared to Zone 4 (1-2 times tree height from the tree strip, but on the same side as Zone 6). The one-to-one line is indicated.









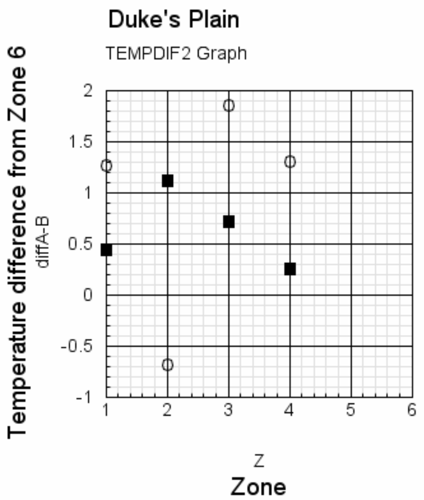


Figure 4.1.10. Comparison of temperatures measured at different zones with Zone 6. Temperature differences were calculated for each day that data was available at each of the two Zones. Minimum temperature difference is indicated by ■ and maximum temperature difference is indicated by ○.

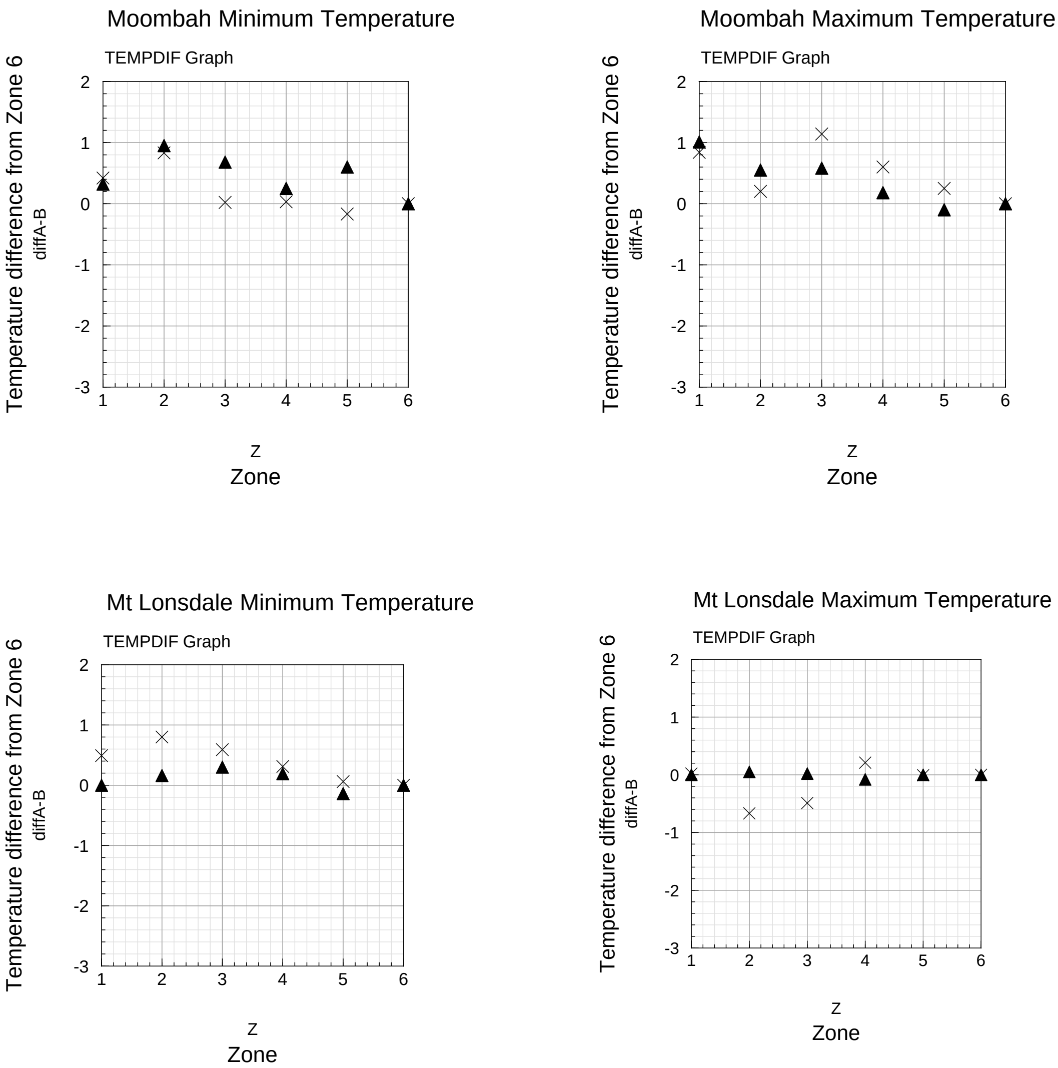


Figure 4.1.11. Comparison of temperature difference between different reps for Mt Lonsdale and Moombah. For Moombah and Mt Lonsdale, Rep 2 is indicated by ▲ and Rep 3 is indicated by ×. For Moombah, Zones 3 to 6 in Rep 2 is on the south side of the strip, whilst Zones 3 to 6 in Rep 3 is on the north side of the strip. For Mt Lonsdale, the strips had different orientation; the tree strip in Rep 2 was parkland with Zones 3 to 6 on the western side, whilst Rep 3 was a more clearly defined tree strip with higher tree basal area (Table 3.1.1) with Zones 3 to 6 on the eastern side of the tree strip.

4.2 Pasture production and composition

4.2.1 Introduction

The influence of tree strips along a perpendicular transect can be assessed in terms of physical and chemical effects on pasture microclimate, soil nutrients and soil water. The response of the biological component of the pasture system is expressed through differences in botanical composition of pasture species, soil micro-organisms, pasture biomass and cover, carbon and nutrient turnover. Grazing animals and management decisions respond to available feed and nutritional value with feedback on biophysical attributes of the system. Given the complexity of the grazed ecosystem a wide range of biophysical measurements have been made to assess the influence of tree strips.

Pasture growth is the major factor that drives the grazing system and determines livestock carrying capacity and animal nutrition (Hall *et al.* 1998). Pasture growth integrates the biophysical attributes described above and hence represents a potential 'bioassay' of the influences of tree strips. In this study, the influence of tree strips on pasture growth was measured by exclosing transects along each strip. The transects were mown in winter each year to remove carry-over pasture material from previous growing seasons. This approach to measuring pasture growth is suitable for tropical grasses where most of the pasture growth accumulates as standing dry matter over the growing season. The effects of grazing were also measured by sampling transects in the adjacent grazed pastures. Comparison of exclosed and grazed pasture attributes is reported in the following study.

4.2.2 Methods

4.2.2.1 Botanal surveys

Pasture botanical composition and the herbage mass of the transects were assessed using BOTANAL (Tothill *et al*. 1978); a rapid assessment technique that estimates relative species composition in terms of the proportional contribution of species to the dry matter yield. It is a combination of the dry-weight-rank technique of t'Mannetje and Haycock (1963) and the comparative yield technique of Haydock and Shaw (1975). Pasture assessments were conducted at Duke's Plain and Mt Lonsdale in April 2004, and all three sites in May 2005. At each location, each replicate was assessed by Zone, and both within the exclosure (ungrazed) and in the adjacent grazed paddock. Within a Zone, three observers assessed 5 individual 0.25m^2 quadrats evenly spread across the zone; giving a total of 15 observations per zone and grazing treatment. The layout of the sampling in each zone and treatment is shown for Duke's Plain, Mt Lonsdale and Moombah in Figure 4.2.1, 4.2.2 and 4.2.3, respectively.

Species were grouped when they were either difficult to identify as they had been eaten (listed as other 3P i.e. desirable perennial grasses) or by family and genius where they could not be identified to species (i.e. *Aristida* spp., and the family Malvaceae). The Malvaceae family were dominated by sidas (*Sida* spp.), desert Chinese lantern (*Abutilon leucopetalum*), and spiked malvastrum (*Malvastrum americanum*); while the Chenopodiaceae where most likely ruby saltbush (*Enchylaena tomentose*), and desert goosefoot (*Chenopodium desertorum*), although many other species were present. Plants where the genus or family were difficult to identify were recorded by functional group: other 3P grasses (Rolfe *et al*. 1997), other native legumes, broad leaved weeds, sown legumes, other native grasses or other introduced legumes.

The comparative yield technique used to assess herbage mass is a double sampling procedure, whereby the herbage yield from sample quadrats is estimated against a set of reference quadrats. Five 0.25 m^2 reference quadrats were selected at each site to represent an interval scale from the least to highest dry matter yield (ranked as 1 to 5, with 1 being the lowest yield). At the end of the survey, an additional 12 quadrats were placed (between the replicates, but not within the sampling area) to cover the range of dry matter yields observed at the site. Each of the observers then ranked the dry matter yield using the 1-to-5 scale, and then the quadrats were clipped, dried (65^{o}C for three days) and weighed to establish a calibration equation between the rank and the actual dry weight. The regression equations were then used to calculate the dry weight per replicate, zone and grazing treatment per observer, then averaged to give an overall site. The calibration equation per observer are given in Appendix 10.1. The data collected was processed in Excel for Windows® using the formulae of Tothill *et al*. 1992) The herbage mass of both the grazed and ungrazed treatment were used to calculate the percentage grazing effect within each zone, calculated from the difference between the grazed and ungrazed and expressed as a percentage per zone.

4.2.2.2 Intensive transect sampling for measuring ‘pasture growth’

Sites were reset by cutting standing dry herbage with brush cutters and slashers, raking into windrows and carrying off site. Duke’s Plain was reset for the 2004 growing season the 22nd July 2003, and Mt Lonsdale was reset on the 2nd September over approximately 5 days per site. In the 2005 growing season, Duke’s Plain was reset on 7th July 2004, Mt Lonsdale on the 16th June 2004, and Moombah on the 23rd June 2004.

The exclosures were mown each year. Cutting height was 5-10cm. After slashing, mowers and brush cutters were used to ensure all grass was cut and that there was no carryover material. The exclosures were then hand raked (over several days) or hay windrowed to remove as much material as possible so as to ensure that grass growth was not impeded by the presence of cut material.

The sites were harvested at the same time as the Botanal surveys, although the harvests took an additional five days to complete per site. At each replicate at each site, 3 transects were established across the tree strips where grass was clipped from 0.25 m^2 quadrats. This intensive sampling was designed to measure annual growth both within the tree strips, and at incremental distances away from the edge of strips, so only the ungrazed treatment (exclosure) was sampled. The layout of the sampling is shown for Duke’s Plain, Mt Lonsdale and Moombah on Figure 4.2.1, 4.2.2 and 4.2.3, respectively.

The transects were established so that a minimum of 8 quadrats were cut from each zone, and the distance between quadrats increased with increasing distance from the edge of the tree strip, giving a greater intensity of clipping near the edge of the tree strip (in Zones 1 and 3). The samples from each quadrat were bagged, dried at 65^{o}C for at least three days to give a dry weight. The dry weights for each replicate were the average of three quadrats. The data are presented as a mean and standard error of the mean.

At each quadrat, total cover, green cover, and litter cover were estimated, and the soil moisture in the 0-10 cm layer was measured using a delta-T soil water probe with measurements taken in milli-volts, and converted into gravimetric moisture content with calibration equations.

4.2.2.3 Tree and shrub species composition

The distribution of trees was measured within the tree strips along four 50 x 2m wide transects, radiating from the centre point within the exclosure, using sampling protocol of Back *et al*. (1999). The projected foliage cover of all trees and shrubs was determined by the point interception method along the same transects using a gimbal ring sighting tube with cross-hairs (Back *et al*. 1997). The percentage cover of the live stems, live leaves, and dead stems were determined from the total number of intercepts, and the height of the trees and shrubs was visually estimated as the height of the dominant tree species at the site, using classifications described by McDonald *et al*. (1990).

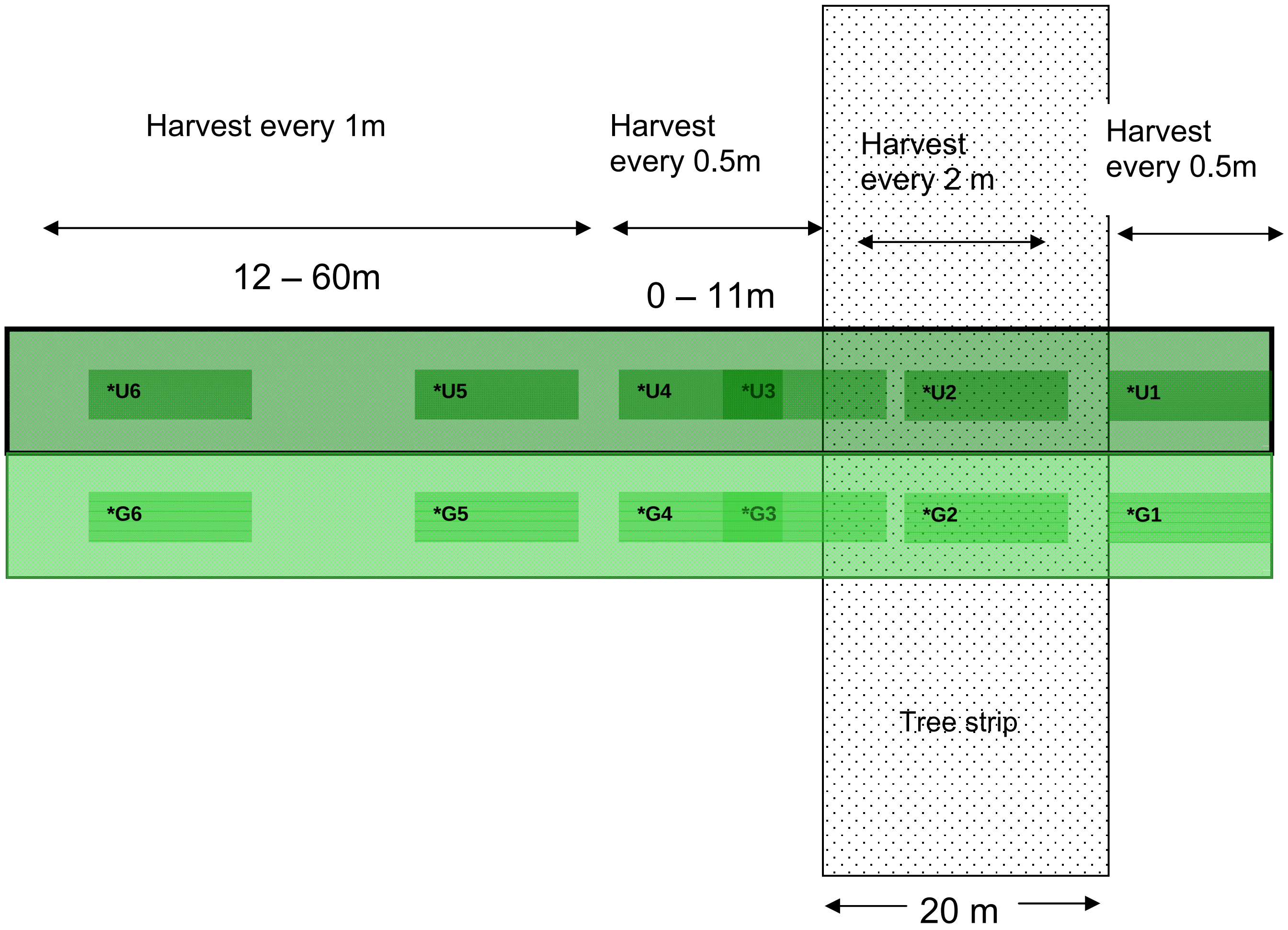


Figure 4.2.1. The sampling layout of the BOTANAL and intensive harvest survey at Duke's Plain.

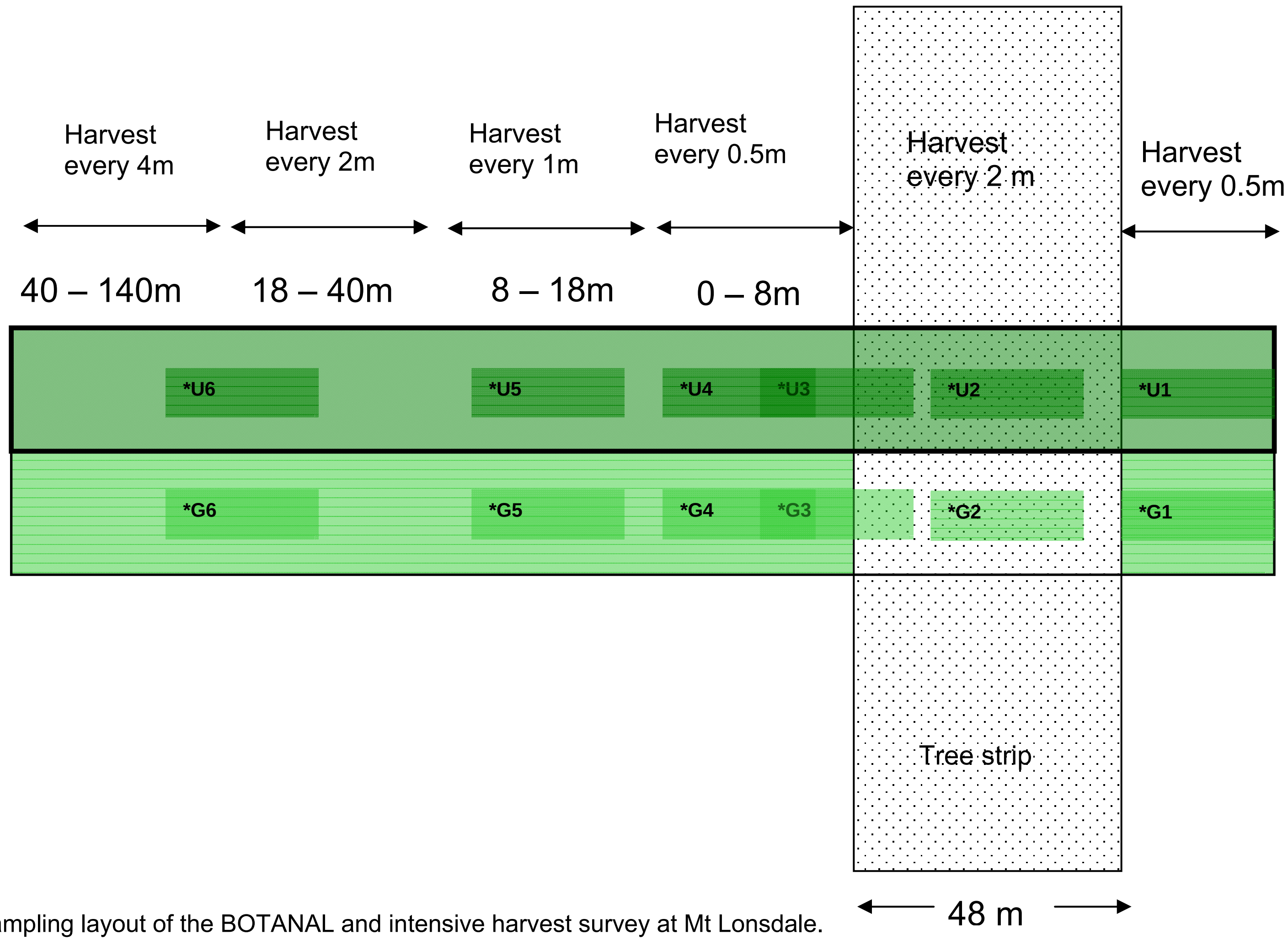


Figure 4.2.2. The sampling layout of the BOTANAL and intensive harvest survey at Mt Lonsdale.

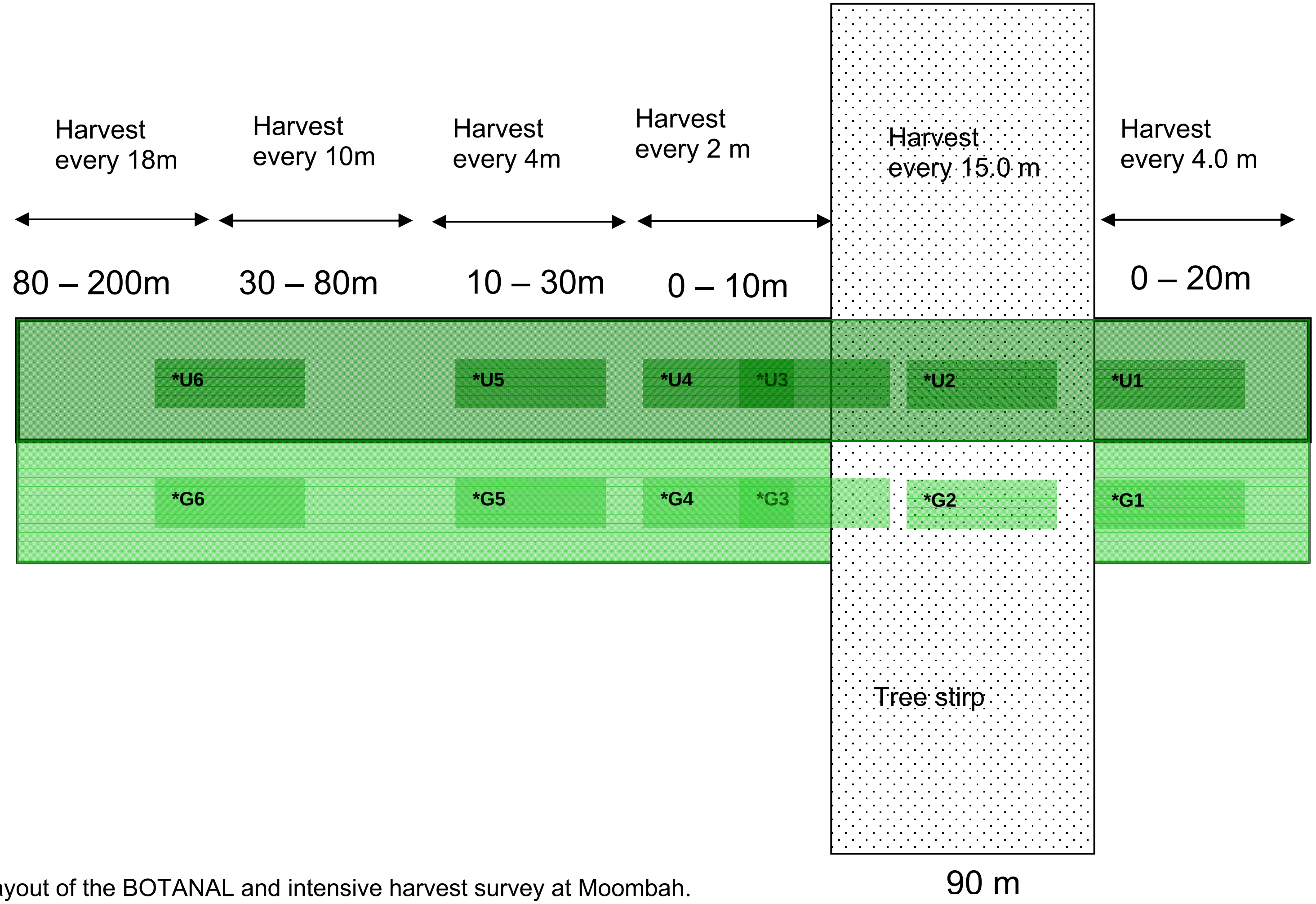


Figure 4.2.3. The sampling layout of the BOTANAL and intensive harvest survey at Moombah.

4.2.3 Results

4.2.3.1 Pasture species composition

Duke's Plain

The mean pasture species composition of the sites for each year are given in Tables 4.2.1 to 4.2.5. The pasture species recorded in all replicates at all sites and years is given in Appendix 10.2. The dominant grasses at Duke's Plain in 2004 (Table 4.2.1) were Gayndah buffel grass (*Cenchrus ciliaris* var *Gayndah)* and Biloela buffel *(Cenchrus ciliaris* var *Biloela*), combined accounting for approximately 90% of the herbage mass in Zones 1 and 3, and 50-60% of the sward in Zones 4, 5 and 6. As the yield of buffel reduced, the presence of Queensland bluegrass (*Dichanthium sericeum*) increased accounting for approximately 30 -50% of the herbage yield in Zones 4 to 6, and increasing in proportion with increasing distance from the tree strips. The bottlewashers (*Enneapogon spp.)* followed a similar trend to Queensland bluegrass, although the overall contribution to herbage mass was lower. Beneath the trees (Zone 2) there was a reduced presence of buffel grass, with green panic (*Panicum maximum* var *trichoglume),* Malvaceae species and broad-leaved weeds accounting for approximately half the herbage yield. There was little difference between the species composition of the grazed and ungrazed treatment, except for Queensland bluegrass which had a slightly higher percentage composition in the ungrazed Zones 5 and 6.

In 2005, both variants of buffel grass continued to dominate the herbage mass in the sward, increasing in their percentage composition across all zones in both the grazed and ungrazed treatments. As in 2004, the percentage of Queensland bluegrass increased in the zones further from the tree strips, although the contribution to the herbage mass was at least half of the 2004 survey. The bottlewashers also followed the same trend as 2004, increasing in dominance away from trees, but also increased in their contribution to herbage yield, accounting for over 10% of the herbage yield in the grazed Zone 5 and 6, and 13% of the yield in the ungrazed Zone 6. Zone 2 had the greatest presence of green panic, the Malvaceae species and broad-leaved weeds, as was the case in 2004, with green panic increasing in its contribution to herbage mass, accounting in 2005 for approximately a quarter of the yield.

Table 4.2.1. Pasture species composition (mean of three replicates, as a % of the herbage yield) from BOTANAL surveys at Duke's Plain in 2004.

Species	Grazed						Ungrazed					
	Zone						Zone					
	1	2	3	4	5	6	1	2	3	4	5	6
Cenchrus ciliaris var. Biloela	11.2	16.0	13.3	24.5	14.7	10.7	21.1	13.1	22.2	20.7	14.5	7.6
Cenchrus ciliaris var Gayndah	79.5	35.4	82.0	45.4	40.1	33.5	64.3	33.7	73.1	55.5	37.8	27.5
Dichanthium sericeum	1.6	2.9	2.2	17.5	25.9	37.6	6.2	0.0	0.0	14.1	34.8	49.6
Panicum maximus var.trichoglum	0.0	19.1	0.0	0.0	0.7	0.0	3.0	25.3	0.0	0.0	0.0	0.0
Heteropogon contortus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7
Bothriochloa bladhii	0.1	0.0	0.0	1.4	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paspalidium caespitosum	0.0	3.5	0.0	0.0	0.0	0.0	0.0	2.3	0.0	0.0	0.0	0.0
Aristida spp.	0.0	0.0	0.0	0.4	0.0	0.1	0.0	0.0	0.0	0.1	0.0	0.0
Other grasses	0.4	0.1	0.0	0.8	0.9	0.1	0.0	0.4	0.0	0.4	0.1	0.1
Rhyncosia minima	0.0	0.0	0.1	5.9	7.2	3.5	0.3	0.0	0.1	4.3	4.4	6.3
Other native legumes	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Broad-leaved weeds	2.3	10.4	1.1	1.8	3.0	1.6	0.4	10.4	1.4	3.4	1.3	2.0
Sporobolus caroli	0.0	1.0	0.0	0.0	0.0	0.4	1.1	0.6	0.4	0.0	0.0	0.0
Enneapogon spp.	3.4	0.1	0.8	0.7	4.6	9.4	2.0	0.4	0.4	1.0	3.4	4.5
Malvaceae	1.5	11.5	0.5	1.4	2.3	3.1	1.0	13.3	2.3	0.8	3.7	1.7
Urochloa mosambicensis	0.1	0.0	0.0	0.0	0.0	0.0	0.6	0.4	0.0	0.0	0.0	0.0

Table 4.2.2. Pasture species composition (mean of three replicates, as a % of the herbage yield) from BOTANAL surveys at Duke's Plain in 2005.

Species	Grazed						Ungrazed					
	Zone						Zone					
	1	2	3	4	5	6	1	2	3	4	5	6
Cenchrus ciliaris var. Biloela	7.9	11.6	9.5	13.6	12.6	13.5	11.0	4.4	21.3	29.3	21.5	9.4
Cenchrus ciliaris var Gayndah	84.1	42.6	87.7	61.4	52.3	46.5	83.2	45.7	76.5	59.9	48.3	41.5
Dichanthium sericeum	0.8	0.6	0.7	4.7	7.4	15.2	2.8	0.0	0.1	5.2	15.7	15.9
Panicum maximus var.trichoglum	2.3	23.8	0.0	0.7	0.0	0.0	0.7	23.5	0.0	0.0	0.3	0.7
Other 3P grasses	0.0	0.0	0.0	0.3	0.3	0.3	0.0	0.0	0.0	0.0	0.7	0.8
Paspalidium caespitosum	0.4	1.5	0.0	0.0	0.3	0.0	0.0	1.1	0.0	0.0	0.0	0.0
Aristida spp.	0.0	0.0	0.0	1.0	0.7	0.7	0.0	1.4	0.0	0.1	0.0	0.0
Eragrostis spp.	0.0	0.0	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	0.3	0.3
Other grasses	0.0	1.9	0.4	0.0	0.4	0.1	0.0	0.1	0.0	0.0	0.0	0.8
Rhyncosia minima	0.0	0.0	0.1	6.8	4.7	0.8	0.1	0.0	0.0	0.5	1.1	1.3
Glycine spp.	0.0	0.0	0.0	0.4	0.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0
Other native legumes	0.0	0.0	0.0	0.0	0.5	0.0	0.0	1.2	0.0	0.0	0.0	0.0
Broad-leaved weeds	0.5	6.5	0.2	0.5	0.3	0.9	0.1	8.4	0.8	0.4	1.5	1.3
Sporobolus caroli	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.5	0.4	0.0	0.0	0.0
Enneapogon spp.	2.6	0.0	1.1	5.2	11.9	10.6	0.9	1.2	0.1	2.3	3.8	13.9
Malvaceae	0.6	10.0	0.4	5.2	4.8	6.9	1.1	8.9	0.4	1.6	5.3	7.9
Urochloa mosambicensis	0.4	1.5	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.5	0.7
Cyperus spp.	0.0	0.0	0.0	0.0	0.3	0.0	0.1	0.9	0.0	0.0	0.0	0.0
Enteropogon spp.	0.5	0.0	0.0	0.1	2.7	4.1	0.1	0.0	0.0	0.0	0.8	5.4
Chenopodiaceae	0.0	0.0	0.0	0.0	0.3	0.0	0.0	1.8	0.4	0.7	0.0	0.0

Mt Lonsdale
At Mt Lonsdale, (Table 4.2.3 and 4.2.4) the sites were dominated by pitted bluegrass (*Bothriochloa decipiens*), Queensland bluegrass (*D. sericeum*), wiregrass species (*Aristida spp*.) and kangaroo grass (*Themeda triandra*). The percentage composition of kangaroo grass and windmill grasses (*Enteropogon* spp.) tended to increase with increasing distance from the tree strips, especially Zone 5 and 6, with an increased proportion of pitted bluegrass and wiregrasses nearer the trees.

In 2004, species numbers were higher than 2005 with 25 different species or groups recorded compared to 16. The dominant species from 2004 continued to dominate, with wiregrasses increasing to approximately 20 - 30% of the herbage mass, and pitted bluegrass contributing about a third of the herbage mass. There were no windmill grasses recorded in the 2005 survey at the site, and the proportion of kangaroo grass dropped by about 10% in the grazed treatment, but increased by about 10% in the ungrazed treatment compared to 2004. Approximately 10-15% of the herbage mass in 2004, and 10-20% of the herbage mass in 2005 was classified as other grasses and broad-leaves weeds. This percentage was higher in the grazed treatment as the grazing and trampling made it difficult to accurately identify all species.

The major differences at Mt Lonsdale compared to Duke's Plain were that: (1) the Mt Lonsdale tree strips did not have a set of species distinct from that of the treeless zones; and (2) while Duke's Plain was dominated by buffel grass, Mt Lonsdale had less than 2% of the herbage mass contributed by Gayndah buffel.

Table 4.2.3. Pasture species composition (mean of three replicates, as a % of the herbage yield) from BOTANAL surveys at Mt Lonsdale in 2004.

Species	Grazed						Ungrazed					
	Zone						Zone					
	1	2	3	4	5	6	1	2	3	4	5	6
Cenchrus ciliaris var Gayndah	1.9	0.0	0.0	1.4	0.3	3.2	0.1	0.0	0.7	0.0	0.3	2.6
Dichanthium sericeum	0.0	6.2	10.2	11.1	11.6	13.4	0.5	4.5	5.5	11.9	15.1	17.6
Panicum maximus var.trichoglum	0.0	0.0	0.0	0.0	0.0	0.0	1.1	0.0	0.0	0.0	0.0	0.0
Bothriochloa decipiens	54.7	28.5	19.7	14.6	14.8	7.1	51.8	23.5	23.2	9.4	8.1	2.5
Heteropogon contortus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.0	0.0
Bothriochloa bladhii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0
Eulalia aurea	4.5	2.3	1.4	1.4	1.7	3.2	6.1	5.1	3.4	5.0	2.5	2.5
Themeda trianda	4.0	10.3	17.0	16.7	24.0	26.0	3.5	14.8	21.7	29.8	31.5	35.2
Other 3P grasses	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Paspalidium caespitosum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0
Iseilema vaginiflorum	0.0	0.7	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0	0.0	1.0
Cymbopogon refractus	0.0	3.5	2.4	0.0	0.0	0.7	0.0	1.8	3.2	3.6	1.9	0.1
Aristida spp.	7.6	15.6	18.1	11.3	6.3	7.2	7.8	21.1	20.8	6.7	5.2	4.2
Eragrostis spp.	1.3	0.0	0.1	0.3	2.4	1.4	1.6	0.0	0.5	1.2	2.9	0.0
Other grasses	10.7	5.4	4.1	9.5	10.7	10.6	6.5	3.8	4.9	4.5	11.9	11.9
Rhyncosia minima	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Glycine spp.	0.3	0.5	0.2	0.6	0.2	0.2	0.9	0.8	0.3	0.1	0.1	0.1
Other native legumes	0.0	0.4	0.0	0.1	0.1	0.0	0.1	0.2	0.1	0.1	0.0	0.2
Broad-leaved weeds	5.7	5.2	6.5	4.5	3.2	2.3	4.8	2.7	1.8	2.4	3.6	2.5
Enneapogon spp.	0.1	0.0	0.1	0.8	0.5	2.3	1.1	0.8	0.0	0.2	0.3	0.0
Malvaceae	0.1	0.1	0.3	0.8	0.6	0.1	2.8	1.0	0.1	0.5	0.2	0.0
Cyperus spp.	0.0	0.5	1.8	0.1	0.1	0.1	0.0	1.8	0.4	0.8	0.6	2.6
Astrebla spp.	0.0	4.3	1.1	2.6	0.7	1.4	2.2	3.3	1.5	1.2	1.1	0.5
Themeda avanacea	0.0	2.8	2.4	6.9	1.8	2.1	3.2	3.6	2.2	7.6	3.3	5.4
Enteropogon spp.	7.3	10.3	13.5	15.2	18.1	14.7	5.7	7.3	5.9	10.3	8.8	9.0
Chrysopogon fallax	1.8	3.3	1.1	2.1	2.6	3.2	0.2	3.2	3.7	4.2	1.5	2.1

Table 4.2.4. Pasture species composition (mean of three replicates, as a % of the herbage yield) from BOTANAL surveys at Mt Lonsdale in 2005.

Species	Grazed						Ungrazed					
	Zone						Zone					
	1	2	3	4	5	6	1	2	3	4	5	6
Cenchrus ciliaris var Gayndah	1.8	0.0	0.1	0.0	0.0	0.7	0.0	1.2	0.8	0.0	1.1	0.0
Dichanthium sericeum	0.0	0.0	2.1	0.4	1.7	0.7	0.6	0.0	0.0	0.0	1.1	0.0
Panicum maximus var.trichoglum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0
Bothriochloa decipiens	35.3	32.5	33.8	22.1	21.9	28.0	33.4	23.4	26.4	20.1	21.1	27.2
Heteropogon contortus	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bothriochloa bladhii	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.8	0.0	0.0	0.0	0.0
Eulalia aurea	0.0	1.4	0.3	1.0	4.5	2.4	0.0	2.9	1.8	2.2	1.9	1.5
Themeda trianda	0.7	5.7	8.2	8.0	7.9	12.7	3.0	16.2	17.6	32.7	42.9	43.2
Cymbopogon refractus	0.0	1.1	2.9	2.5	0.1	0.8	0.0	0.1	3.0	4.5	2.5	1.8
Aristida spp.	23.0	20.8	22.4	20.2	10.5	7.2	30.1	32.5	28.2	18.0	5.1	6.8
Eragrostis spp.	4.0	0.1	0.0	1.1	1.9	1.1	0.7	0.0	0.7	0.1	0.4	0.0
Other grasses	9.7	11.2	7.0	15.3	17.3	19.4	3.5	5.9	6.4	10.0	8.4	6.3
Glycine spp.	0.0	1.1	0.5	1.2	0.5	0.1	0.7	1.1	0.2	0.1	0.0	0.1
Other native legumes	0.1	0.4	0.4	0.0	0.1	0.4	0.0	0.0	0.0	0.0	0.4	0.1
Broad-leaved weeds	6.1	1.8	3.7	3.7	3.7	1.5	6.3	2.4	0.7	1.4	2.2	1.0
Enneapogon spp.	1.3	1.5	0.3	7.4	3.8	2.4	2.6	1.4	1.6	1.5	4.0	2.6

Moombah

The Moombah treeless zones were dominated by Biloela buffel grass (*C. ciliaris* var *Biloela),* broad-leaves-weeds and Chenopodiaceae (Table 4.2.5). In Zone 2, there was little buffel grass present, with wiregrass (*Aristida spp.),* Hooky grass (*Ancistrachne uncinulata*) and broad-leaved-weeds all found in higher proportions than the treeless zones. The buffel grass tended to contribute a higher percentage of the herbage mass in the zones adjacent to the tree strip (Zones 1 and 3), reducing slightly with distance from the strip edge. The Chenopodiaceae species tended to be found near areas of recent disturbance or ash beds that were formed when cleared timber was windrowed and burnt, and these tended to be found in Zones 1 and 4. Shot grass (*Paspalidium globoideum)* tended to increase in percentage contribution to herbage mass with distance, being greatest in Zones 5 and 6. There were few consistent differences between the grazed and ungrazed treatments to report.

Table 4.2.5. Pasture species composition (mean of three replicates, as a % of the herbage yield) from BOTANAL surveys at Moombah in 2005.

Species	Grazed						Ungrazed					
	Zone						Zone					
	1	2	3	4	5	6	1	2	3	4	5	6
Cenchrus ciliaris var Biloela	60.3	1.0	55.8	39.1	37.8	41.6	42.0	0.6	54.9	39.2	45.5	51.0
Dichanthium sericeum	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Panicum maximus var.trichoglum	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bothriochloa decipiens	0.0	0.0	0.0	0.7	0.2	0.0	0.4	1.4	1.5	1.6	0.5	0.0
Themeda trianda	0.0	0.0	0.0	0.4	0.0	0.0	0.0	0.4	0.0	0.0	0.8	0.0
Paspalidium caespitosum	0.0	2.0	0.4	0.0	0.3	0.0	0.0	0.1	0.0	0.0	0.0	0.0
Cymbopogon refractus	0.0	0.4	0.1	0.0	0.1	0.8	0.0	1.8	1.1	0.0	0.4	0.4
Aristida spp.	0.2	7.4	4.2	1.0	4.5	2.2	1.9	5.7	0.8	1.5	2.7	1.5
Eragrostis spp.	0.1	0.0	0.4	1.2	0.4	0.0	0.0	0.0	0.4	1.1	0.1	0.4
Other grasses	0.4	3.1	3.6	6.8	5.1	4.8	0.4	2.8	4.7	3.3	5.5	2.6
Glycine spp.	0.8	1.2	0.1	0.0	0.0	0.0	0.0	2.5	0.0	0.0	0.0	0.0
Other native legumes	0.0	2.4	0.0	0.1	0.1	0.0	0.4	1.0	0.0	0.1	0.1	0.1
Broad-leaved weeds	9.6	40.5	7.9	11.2	10.8	8.0	11.1	35.1	13.9	13.6	5.6	6.1
Sown legumes	0.0	0.0	0.0	0.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sporobolus caroli	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
Enneapogon spp.	0.8	0.0	2.9	0.9	8.0	5.7	3.3	0.0	0.5	2.4	2.7	0.9
Cyperus spp.	0.0	2.7	1.3	0.0	0.5	0.4	0.0	3.3	0.0	0.4	0.4	0.1
Enteropogon spp.	1.3	1.9	2.0	4.6	3.5	3.2	3.3	0.0	2.9	2.0	1.2	1.3
Chrysopogon fallax	1.2	0.0	1.9	1.2	1.5	1.8	0.3	3.6	0.8	1.7	0.8	0.2
Paspalidium globoideum	3.7	7.8	2.3	13.9	14.7	20.6	3.3	2.7	5.5	6.0	13.5	11.5
Ancistrachne uncinulata	4.7	25.4	2.7	1.2	2.2	0.1	5.7	37.3	0.4	3.2	0.7	0.0
Chenopodiaceae	16.8	4.2	14.4	16.9	10.2	10.9	27.9	1.8	12.6	23.9	19.6	24.1

4.2.3.2 Herbage mass estimates and grazing effect

The relative grazing effect was calculated as the percentage decrease of grazed compared to ungrazed herbage mass. The grazing effect represents the combined impact of grazing through intake, trampling and grazing feedback on herbage growth (i.e. likely reduced root activity, increased water stress and reduced nutrient uptake).

Duke's Plain
The herbage mass of each zone and treatment as estimated in the BOTANAL surveys of Duke's Plain are presented in Figure 4.2.4 (2004) and Figure 4.2.5 (2005). There was a much greater herbage mass recorded in 2004 compared to 2005 for all zones and treatments. The grazed treatment had a lower herbage mass, with the greatest levels of grazing rate observed in Zones 4 and 5. In the 2004 survey, the relative grazing effect in Zones 4 and 5 were approximately 46%, whereas they were between 17- 22% for Zones 1, 2 and 3, and as low as 2% in Zone 6. The grazing effect in 2005 was significantly greater in all Zones, with Zones 3 and 4 at approximately 72%, Zones 1 and 5 at 68%, Zone 2 at 65%, and Zone 6 again the lowest but far higher than the previous year at 58%. The impact of grazing was to remove the peak in the herbage mass observed in the ungrazed treatments in Zones 4 and 5.

Mt Lonsdale
The herbage mass of each zone and treatment for Mt Lonsdale is given in Figure 4.2.6 (2004) and Figure 4.2.7 (2005). There was a far greater herbage mass recorded in the 2004 survey than the 2005, with a decrease of 1000-1500 kg/ha. The grazed treatment had a lower observed herbage mass, with the greatest levels of grazing effect in Zones 3, 4 and 5 of 27%, 25% and 32% respectively. The grazing rate in Zones 2 and 6 were about 20%, while in Zone 1 there was little grazing rate at only 5%. The grazing effect in 2005 was substantially higher, with greater than 40% across all zones. The levels of grazing effect were highest in Zones 5 and 6, at 70% and 79% respectively, with Zone 4 at 59% and Zone 3 at 53%. There was an increasing level of grazing effect with distance from tree in the 2005 survey. The grazing effect in Zone 1 was again the lowest at 43%, with greater reduction (53%) in the tree strips in 2005. As with Duke's Plain, the effect of grazing was to remove the peak in herbage mass in the Zones 4 and 5.

Moombah
The herbage mass of each zone and treatment for Moombah in 2005 is shown in Figure 4.2.8. The herbage mass was greater in the ungrazed treatment, with Zone 2 having less than half of the herbage mass than all other zones. The greatest levels of grazing effect were observed at Zone 3, at 58% reduction in herbage mass. Reduction in Zones 2, 4 and 5 was 34%, 36% and 38%, respectively. The grazing effect in Zone 6 was 44%. As with the other sites, the effect of the grazing was to remove the peak in the herbage yield found at distances away from tree edge, although the effects at Moombah was not as clear as the other two sites. In part, this was due to the impact that the recent clearing treatment has had, with ashbeds and disturbed ground found at the margins of Zone 1 and 4.

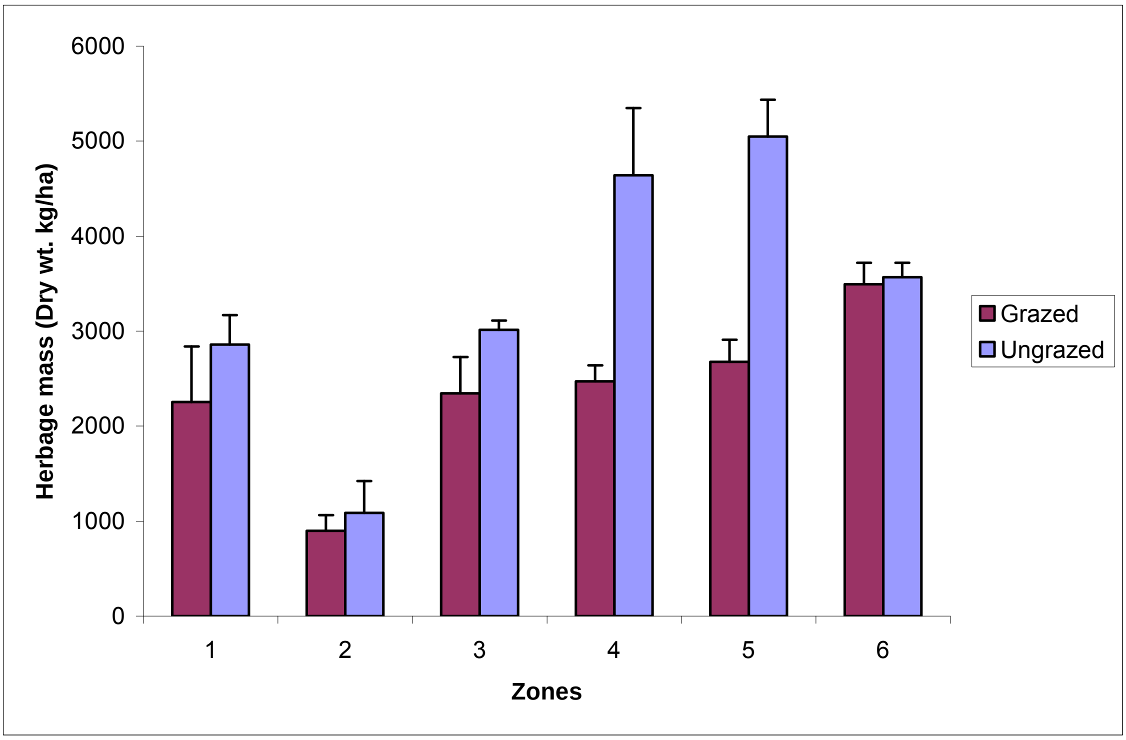


Figure 4.2.4. Duke's Plain 2004 BOTANAL herbage mass estimate comparing the grazed and ungrazed treatments by zone. Standard error bars are shown.

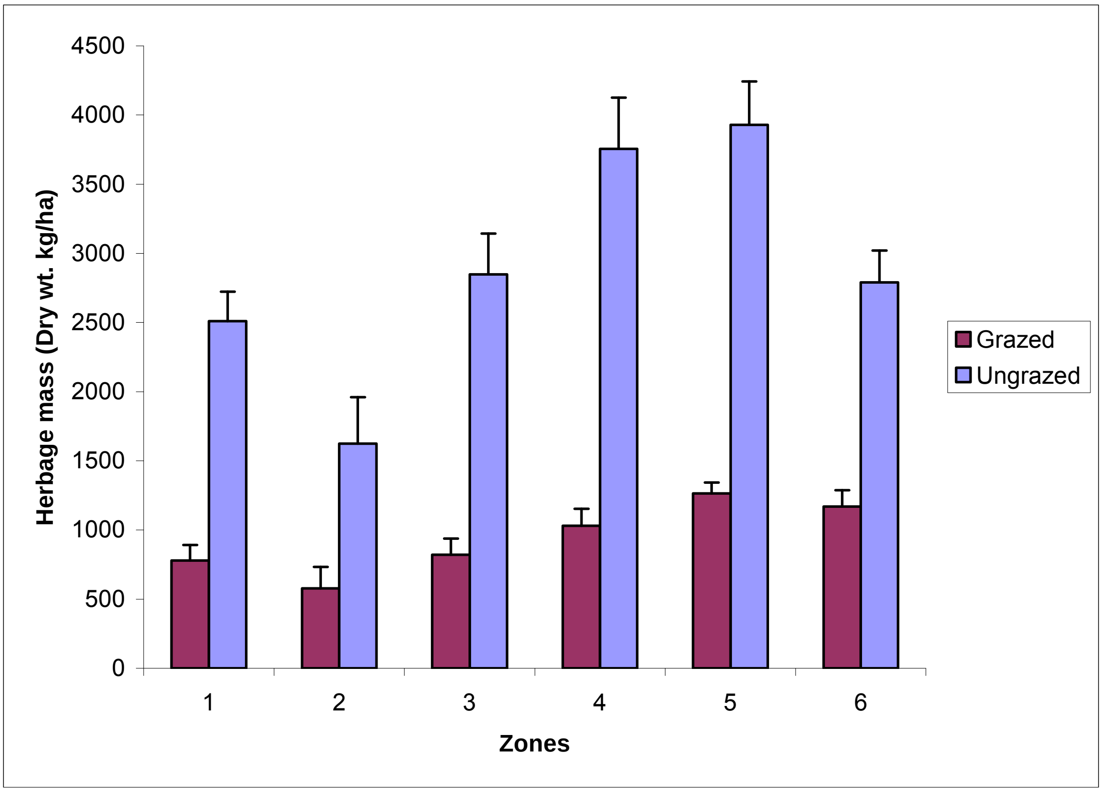


Figure 4.2.5. Duke's Plain 2005 BOTANAL herbage mass estimate comparing the grazed and ungrazed treatments by zone

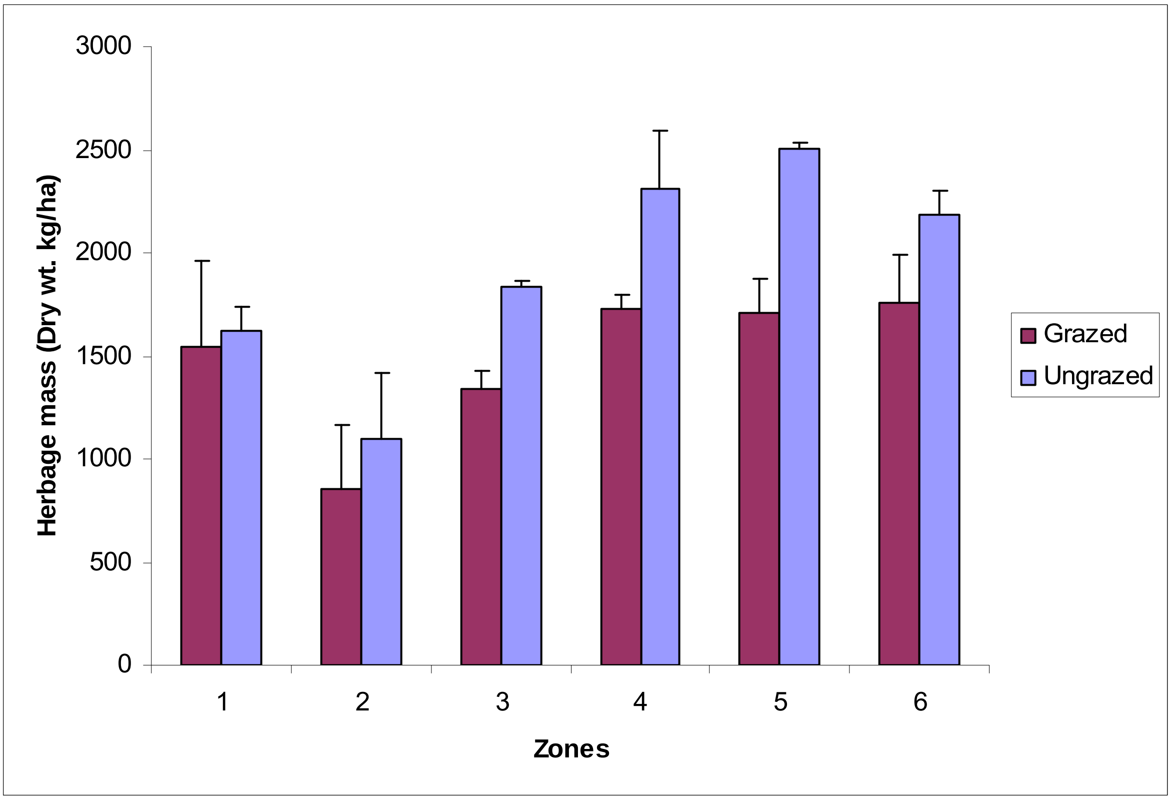


Figure 4.2.6. Mt Lonsdale 2004 BOTANAL herbage mass estimate comparing the grazed and ungrazed treatments by zone.

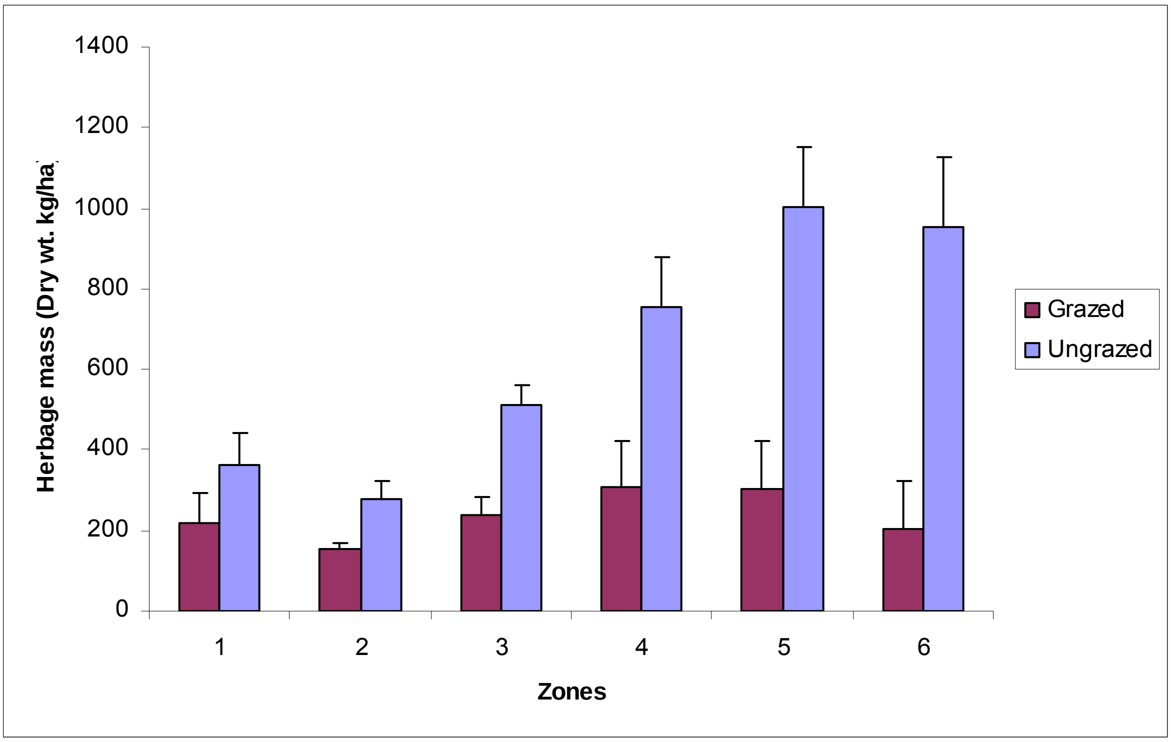


Figure 4.2.7. Mt Lonsdale 2005 BOTANAL herbage mass estimate comparing the grazed and ungrazed treatments by zone.

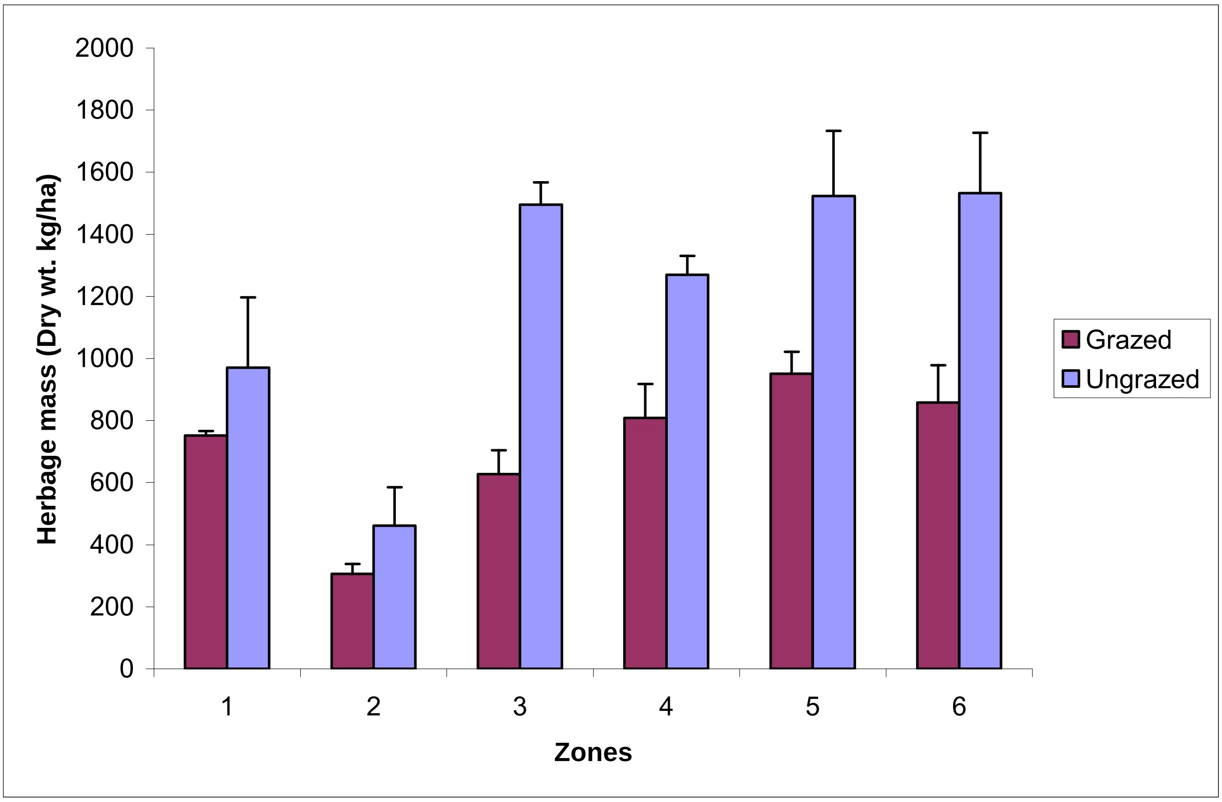


Figure 4.2.8. Moombah 2005 BOTANAL herbage mass estimate comparing the grazed and ungrazed treatments by zone.

4.2.3.3 Intensive survey yield and cover estimates

A major objective of the project was to investigate potential tree strip effects by intensive sampling along pasture transects perpendicular to the tree strips. Figures 4.2.9 to 4.2.11 show the measurements for each of the 3 sites. Running means using 4 adjacent quadrats were calculated and plotted against the running mean of transect distance. Pasture variables, i.e. standing dry matter, total pasture cover, green cover and litter cover are presented for the 3 tree strips at each location. In a further analysis, data from Zones 2 to 6 are compared across the five locations x year combinations. Following the analysis reported below, a rapid follow-up survey was made (December 2006, Appendix 10.9) to investigate possible sources of variation. The results from this survey are yet to be incorporated in the interpretation of the intensively sampled transects.

Duke's Plain
The transect of standing dry matter for 2004 and 2005 (Figures 4.2.9A and B) show the 'U-shaped' effect of the tree strip with low yields within the tree strip and rapidly increasing standing dry matter at the furthest edges of Zone 1 and Zone 3. Peak yields in 2004 occurred at 40 metres (approximately 14 metres from the edge of the strip, representing 2.2 x tree height). There was a general decline in yield out to Zone 6 (53 metres from the edge of the strip, or 8 x tree height). The yields in 2005 showed a similar 'U-shaped' pattern, although the zone of peak yield and decline to Zone 6 was quite variable between replicates.

At Duke's Plain it is unlikely that frosts had occurred before sampling. SILO daily climate surface data for Cracow, the nearest meteorological station (25 km from site) reporting temperature indicated screen minimum temperature of 2.5^{o}C on 13 May 2004 at the time of sampling (12-16 May 2004). Minimum temperature of 2^{o}C in the screen can be associated with frost. Colder temperatures more likely to be associated with frost did not occur until the end of May. The measured values at Duke's Plain had substantially higher minimum temperatures than the SILO data during this period. In 2005 minimum temperatures likely to be associated with frost did not occur (27 May) until after sampling (9-11 May 2005). Green cover values were low across most of the transect, and zero in Zone 1 and within the tree strip. Although low, green cover values in 2004 showed a distinct peak at 30-35 metres (3-7.5 metres from the edge of the tree strip, or 0.5-1.1 x tree height). Green cover values declined from a mean peak of 14% to 7% at the end of the transect (Zone 6). The sampling in May 2005 occurred two weeks before the likely first frost, and hence the pattern of green cover values across the transect are more likely to indicate the effects of soil water stress and evaporative demand. There were substantial differences between the tree strips, with Replicate 3 having higher green covers across the whole transect. The reasons for the large differences between Replicates 2 and 3 in terms of green cover are not clear at this stage of analysis.

Total pasture cover in 2004 and 2005 reflected the 'U-shaped' pattern of pasture standing dry matter. In 2004 there was higher cover in Zones 1 and 2, probably reflecting the effects of tree litter (Figure 4.2.9). Over most of the transect, total cover values were high, including a substantial component of litter cover. As a result, runoff would be expected to be low. An interesting feature of the transects of cover in 2004 is the 'dip' in two replicates at approximately 30 metres (2.5 metres from the edge of the tree strip). Both total cover and litter cover show this effect and maybe the result of previous grazing history as in the second year of exclosure (2005) there was no 'dip' in this zone.

Mt Lonsdale

The transect of standing dry matter for 2004 (Figures 4.2.10A) show the 'J-shaped' effect of the tree strip with low yields within the tree strip and Zone 1. In 2005 (Figure 4.2.10B) the 'U-shaped' pattern was more distinct than in 2004. In both years, there was a peak of standing dry matter at approximately 90-110 metres (representing 20-40 metres from the edge of the tree strip, or 1-2.4 x tree height). In 2004 there was an average decline to the end of the transect (200 metres, representing 130 metres from the edge of the tree strip, or 7 x tree height). The decline to the end of Zone 6 was not as clear in 2005. Replicate 2 at Mt Lonsdale was substantially different to the other tree strips in the study, in that tree basal area was low and the replicate had a park-like appearance. Nevertheless, the standing dry matter in 2004 showed a distinct peak at 90 metres and a rapid decline to 150 metres (80 metres from the edge of the tree strip, or 4.4 x tree height). Yields in Zone 6 for this replicate were substantially lower than for the other replicates in both years although the cause is yet to be determined.

It is not clear whether frosts had occurred before sampling in 2004 (24-30 May) at Mt Lonsdale. The measurements indicated minimum temperatures were only measured at the site in 2005. Measured minimum temperatures were 1-2^{o}C less than calculated in the SILO daily climate surfaces. The SILO data for 2004 indicated low screen temperatures (<2.5^{o}C) or 12, 13, 17 and 28th May 2004 when frosts were possible prior to sampling. However, the high observed green cover (≈30%) suggest little impact on pasture senescence.

Green covers in Zones 1 and 2 were very low, rapidly increasing as with pasture standing dry matter, to peak at 30-40% (80 metres, or 10 metres from the edge of the tree strip, and 110 metres, or 40 metres from the edge of the tree strip, representing 0.5 and 2.2 x tree height). For Replicates 1 and 2 there was a general decline to the end of the transect (200 metres, 130 metres from the edge of the tree strip, or 7 x tree height). In 2005, pasture sampling (11 May 2005) occurred 10 days before the likely first frost (21 May 2005). Green covers were generally lower than 2004, reflecting the drier growing season.

Total cover in 2004, and to a lesser extent in 2005, indicated a maximum at 100-150 metres on the transect, representing 30-80 metres from the edge of the tree strip, or 1.6-4.4 x tree height. In 2004, litter cover was highest at approximately 50 metres in the middle of the tree strip. In 2005, transect patterns were less distinct. For most of the zones away from the tree strip (> 70 metres), covers were high (> 60% in 2004 and > 30% in 2005) reducing the likelihood of runoff.

Moombah
The transect of standing dry matter for 2005 (Figure 4.2.11A) showed a classic, almost symmetrical 'U-shaped' effect of the tree strip with low yields within the tree strip. Peak yields occurred at approximately 110-120 metres, being from the edge of the tree strip to 10 metres distant. Tree height at Moombah was variable with mature popular box at 20 metres height but with the dominant shrub component at 8-12 metres height (Section 4.2.3.4). Thus, the peak yields at Moombah were within 0.5-1 x tree height of the tree strip. Pasture yields reached a plateau from 130-300 metres, that is 20-200 metres from the edge of the tree strip, representing distances greater than 1-2 x tree height, depending on which tree or shrub height component is considered.

The 2005 sampling occurred (15 May 2005) approximately 2 weeks before the likely occurrence of the first frost (28 May 2005). Green covers were high over most of the transect (approximately 20-40%) and showed a similar peak at the distance of peak standing dry matter yield, namely 110-120 metres, i.e. from the edge of the tree strip to 10 metres away. There was considerable variation between the replicates in terms of green cover in Zone 1 and 2, with Replicate 3 having the highest green cover at the start of the transect (i.e. 0 metres, 20 metres from the edge of the tree strip). In this replicate, Zone 1 was on the south side of the tree strip, and hence was likely to have received more shade. Replicate 2 had greater green cover within the tree strip

Total cover in 2005 had a similar 'U-shape' pattern to standing dry matter, with peaks at 120 metres (10 metres from the edge of the tree strip). There was a plateau in cover from 150-300 metres of 30-50%. Litter covers were high in the tree strip (20-110 metres

Green cover analysis
Green cover is a measure of yield, moisture stress, evaporative demand and frost. Field observations would suggest that green cover is particularly sensitive to shading, specifically where pastures are protected from afternoon sun. The presence of trees also has strong impacts on frost in terms of providing radiative warmth and changes in wind flow pattern at night. Thus, green cover provides an index of the patterns of influence of the tree strips. Table 4.2.6 summarises the green cover estimates for each location and replicate. The transect patterns of green cover for the location x year combinations are given in Figure 4.2.12. In 2004, it was possible that the

pastures were sampled after frost had occurred, and hence the peaks in green cover were closer to the tree strip than in 2005 when it was unlikely that frost had occurred. In 2005 the peaks in green cover were further from the tree strip, suggesting a beneficial influence of trees several multiples of height away from the tree strip.

The green cover data for the three locations (Figure 4.2.12) indicated higher green covers in the vicinity of the tree strips supporting the hypothesis that the effects of shading on senescence should be included in model representation (see Section 4.7). When observed green cover measurements were expressed as a ratio to observed pasture SDM, three location x year combinations indicated greater green cover per unit of SDM from edge of tree strip to 1-2 x tree height away from the tree strip (Figure 4.2.13).

At Moombah, the tree strips ran east-west. In the transects of Replicate 1 and 2, Zone 1 was on the north side, i.e. exposed to afternoon sun, whilst in Replicate 3, Zone 1 was on the south side (Zone 3 had the reverse aspect). The results suggested that zones that were shaded, i.e. Zone 1 in Replicate 3, and Zone 3 in Replicates 1 and 2, had higher green cover than the zones on the opposite side of the tree strip.

4.2.3.4 Discussion and Conclusion

Appendix 10.9 describes the general features of individual replicates in terms of pasture composition, micro-topography, clearing debris and trees, ash beds and pasture establishment history. A summary of how these factors could effect pasture growth is given below.

Duke's Plain
At Duke's Plain, there were differences in species composition along the transect and between the replicates, with implications for plant growth in terms of nitrogen and water use efficiency: e.g. Biloela Buffel with more stem, Gayndah Buffel with more leaf and Queensland Bluegrass with less robust leaf and stem (hence less dry matter weight for observed cover). In Rep1 near the tree strip, there was also an area of potential run-on from grazed areas on the other side of the tree strip.

Mt Lonsdale
At Mt Lonsdale, in Rep1 there was a change in soil type from sandy surface to 'linear gilgai' features at about 25-30 metres from the tree strip edge. The hill-channel feature of the gilgai component of the transect appeared to offer the opportunity of runoff from the adjacent grazed area to concentrate in run-on channels. There was also likely to be an interaction with fallen trees left after clearing and run-on areas. In Rep2, there were important bands of fallen timber parallel with the tree strip, as well as small drainage lines that could provide run-on through the transect, especially at the point of peak yield (20 metres from edge of tree strip). Rep3 similarly had fallen timber associated with the position of peak yields. Thus the surface features of the transects may have been contributing to the measured 'beneficial' effects in the zones near the tree strip compared to the zones furthest from the tree strip.

Moombah
At Moombah, the average peak pasture yield was measured at a distance 0.5 to 1 multiples of tree height from the tree strip (6-12 metres). This was due to the fact that at the time of the original clearing and stick raking (1999), the 5-7m edge of the pasture adjacent to both sides of the tree strip was planted to buffel grass from a

seed box on the back of the stick rake. The rest of the transect was not sown until several years later and after the timber had been burnt. As a consequence, there was a higher density of buffel grass plants immediately adjacent to the tree strip, and then two major ash beds with associated fire effects across the transect (i.e. parallel to the tree strip). Thus, the location of peak yield and the high variability in pasture yields along the transect reflects clearing and pasture establishment practices rather than tree strip effects themselves.

There is a danger in attributing all of the enhancement of pasture growth to the effect of tree strips on pasture microclimate. Other factors affecting redistribution of surface runoff such as micro-topography and debris from clearing, (e.g. logs), could have had a major impact on available soil water and nutrients. For example, observations at Mt Lonsdale (G. Stone and G. Fraser personal communication) in November 2006 indicated evidence of runoff and run-on areas associated with linear gilgai microrelief (Plate 3.1) developing into a significant drainage line. These underlying soil effects on water redistribution were most apparent at the start of the 2006/07 growing season, following a long period of drought and low cover (Plate 4.1, Appendix 10.9). Orientation and distribution of tree debris from clearing was also likely to have contributed to ponding and variation in quadrat yields along the transect. Whilst still important, these soil effects were not apparent under conditions of higher pasture growth in 2004.

The above study of intensive sampling of pasture standing dry matter and other pasture attributes demonstrates the power of pasture growth as a bioassay of the influence of tree strips. The results suggest that both the beneficial effects of tree strips on pasture microclimate, need to be considered. A general relationship across locations and year combinations between pasture standing dry matter, as a measure of pasture growth is developed in section 4.5.

Table 4.2.6. Analysis of green cover from intensive pasture transects.

Location	Year	Replicate	% Green Cover across Zone 1[A] from outside to strip	% Peak Green Cover	Transect Distance at Peak Green Cover	Distance of Peak Green Cover from Edge of Zone 2 (i.e. Tree Strip)	% Green Cover across Zones 5 and 6[B]	Distance of Peak Green Cover as a Multiple of Tree Height
Duke's Plain	2004	1	Zero	17	30	2.5	8	0.38
		2	Zero	12	35	7.5	8	1.15
		3	Zero	19	30	2.5	5-10	0.38
		Mean	Zero	14	30	2.5		0.38
Comment:	*Effect at less than 1/2 height (6.5m).*							
Duke's Plain	2005	1	2 – 4	13	60	32.5	8	5.00
		2	2 – 3	8	40	12.5	2 – 7	1.92
		3	20	50	50 - 60	17.5	30	2.70
		Mean	9	22	60	32.5		5.00
Comment:	*Effect at 3-5 x height (6.5m) sampling before frost.*							
Mt Lonsdale	2004	1	3	41	110	40	32	2.22
		2	4	34	80	10	26-20	0.56
		3	4	34*	80*	10	36 decline to 22	0.56
		Mean	2 – 4	34	80	10		0.56
Comment:	**2 peaks, distance to first peak shown. Effect about ½ height (18m) of trees. .*							
Mt Lonsdale	2005	1	10	12	100	30	8.4	1.67
		2	-	-	-	-	-	-
		3	2 – 6	9.5	75	5	2	0.28
		Mean	7 – 8	8	20 - 40			-
Comment:	*Effect at 1 ½ height (18m) in drought year sampling before frost.*							
Moombah	2005	1	19 – 2	22	125	15	20 – 30	1.25
		2	30 – 50	45	120 – 140	10 – 30	35	0.83 – 2.5
		3	46 – 4	60	118	8	30	0.67
		Mean	31 – 12	42	118	8	30	0.67

Notes - Rep3 less disturbed, Zone 1 on south side of strip; Reps1 and 2, Zone 1 on north side of strip.
[A] From outside to edge of tree strip.
[B] From Zone 5 to end of Zone 6.

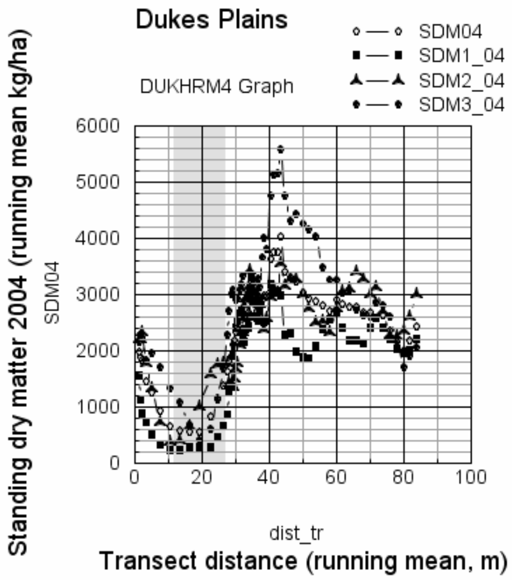


Figure 4.2.9a.

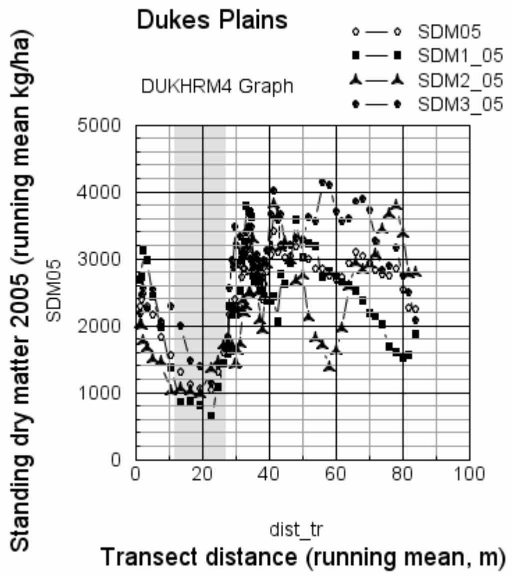


Figure 4.2.9b.

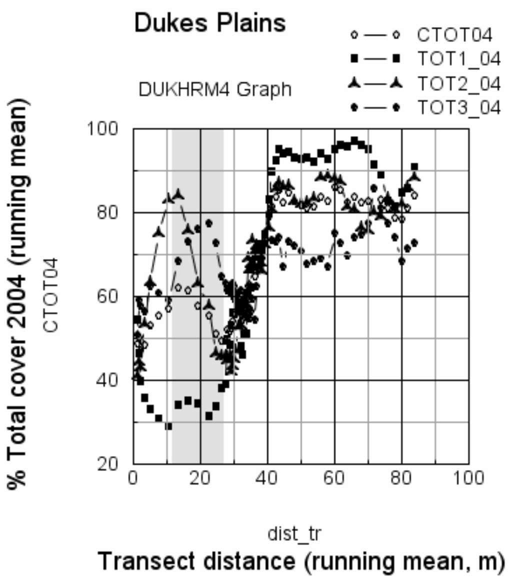
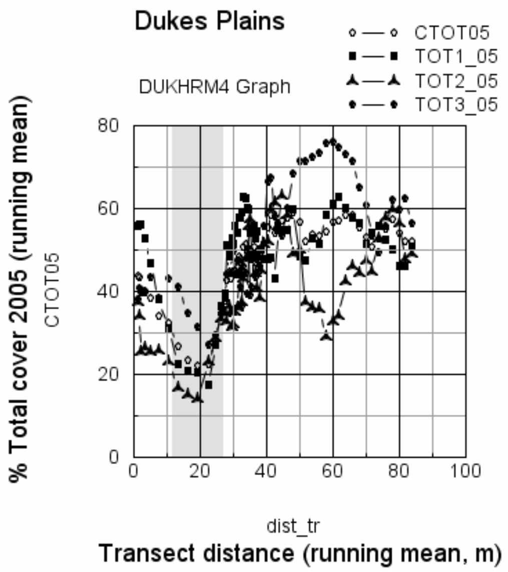


Figure 4.2.9c.



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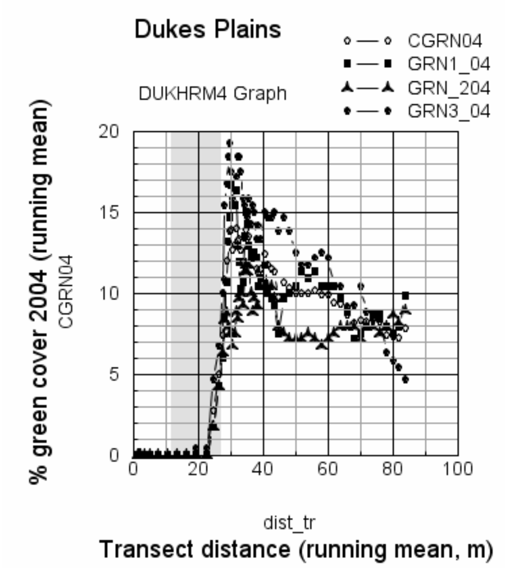


Figure 4.2.9e.

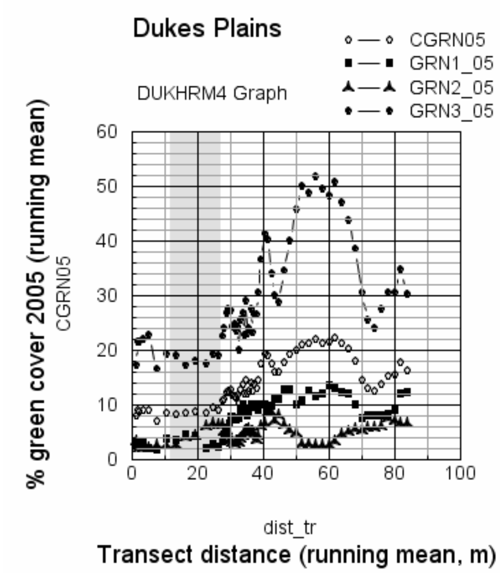


Figure 4.2.9f.

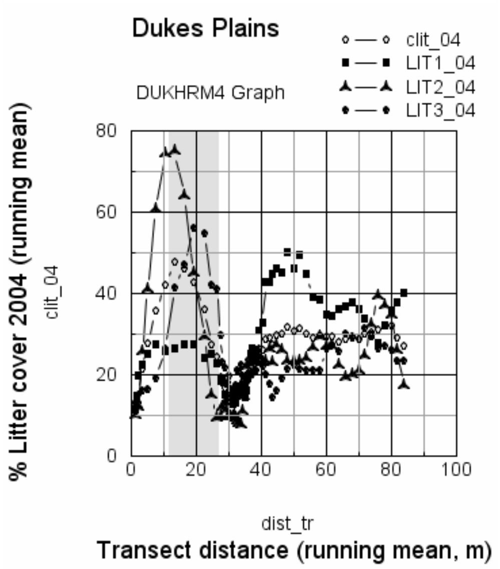


Figure 4.2.9g.

Figure 4.2.9. The relationship between transect distance (running mean) and standing dry matter (SDM), total cover (TOT), green cover (GRN) and litter cover (LIT) for 2004 and 2005 at Duke's Plain. Figure (a) is standing dry matter for 2004; Figure (b) is standing dry matter for 2005; Figure (c) is total cover for 2004; Figure (d) is total cover for 2005; Figure (e) is green cover for 2004; Figure (f) is green cover for 2005; Figure (g) is litter cover for 2004. Replicates 1, 2 and 3 are shown as well as the mean of the 3 reps.

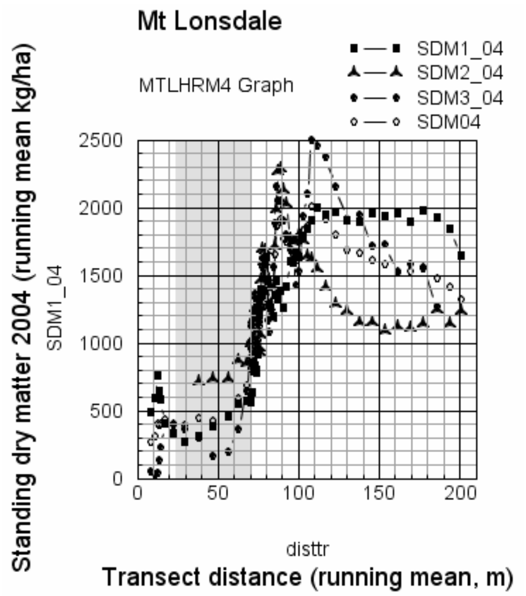
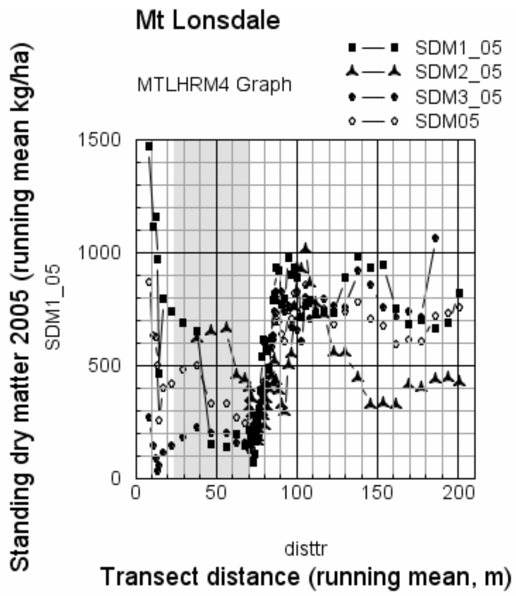


Figure 4.2.10a.



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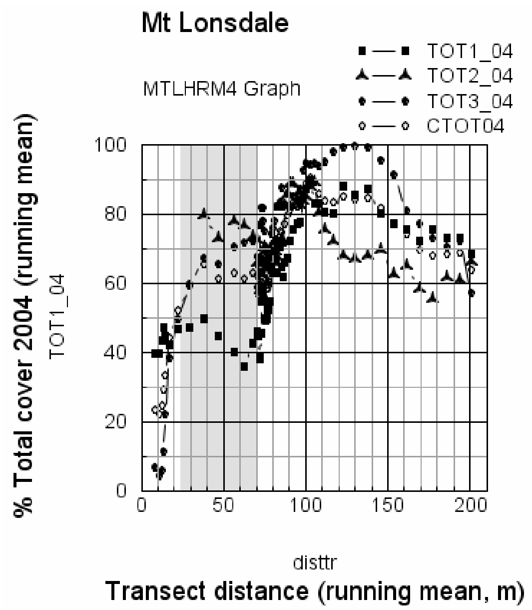

Figure 4.2.10c.

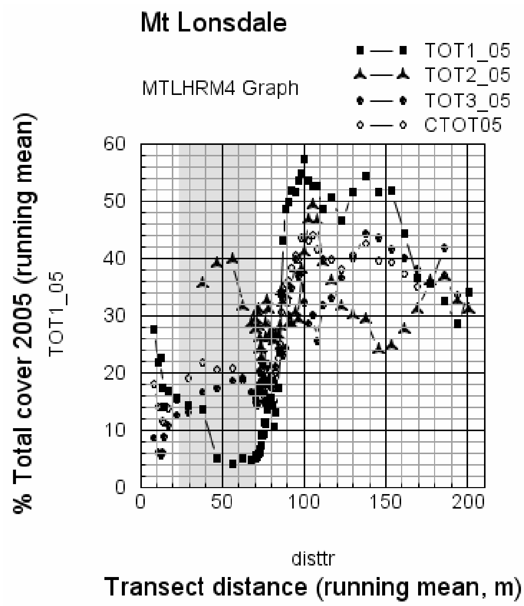

Figure 4.2.10d.

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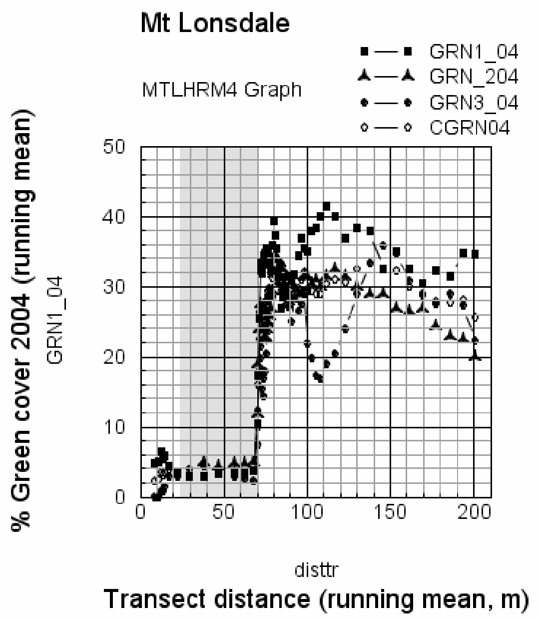
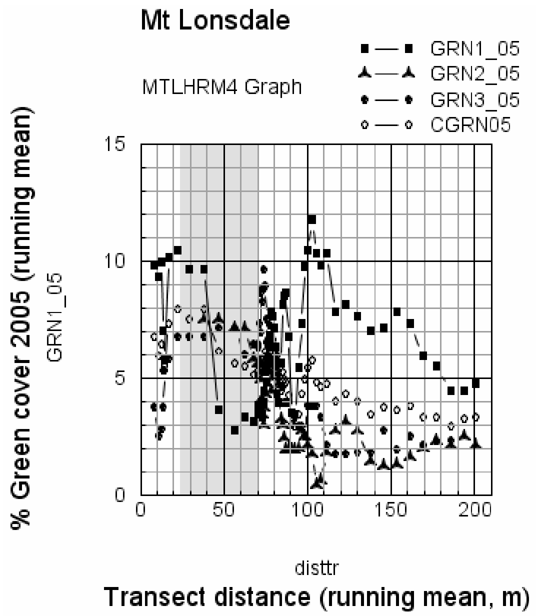


Figure 4.2.10e.



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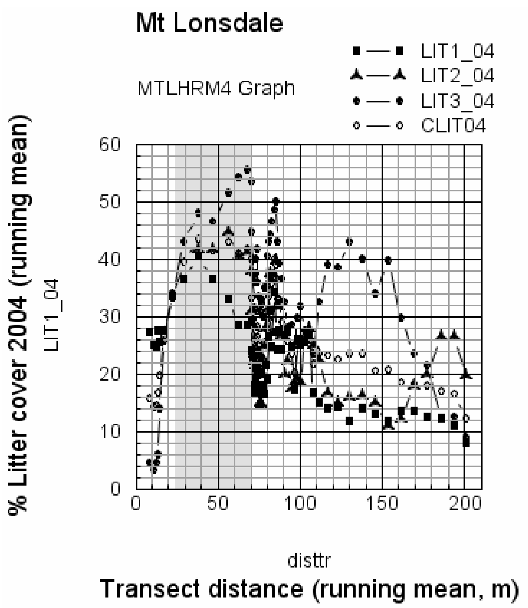


Figure 4.2.10g.

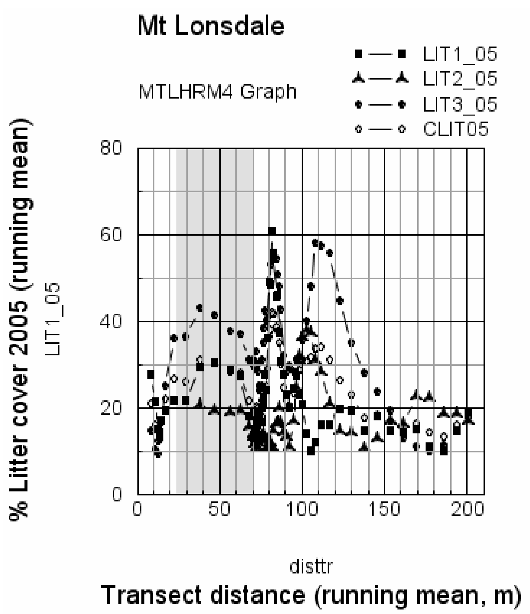


Figure 4.2.10h.

Figure 4.2.10. The relationship between transect distance (running mean) and standing dry matter (SDM), total cover (TOT), green cover (GRN) and litter cover (LIT) for 2004 and 2005 at Mt Lonsdale. Figure (a) is standing dry matter for 2004; Figure (b) is standing dry matter for 2005; Figure (c) is total cover for 2004; Figure (d) is total cover for 2005; Figure (e) is green cover for 2004; Figure (f) is green cover for 2005; Figure (g) is litter cover for 2004; Figure (h) is litter cover for 2005. Replicates 1, 2 and 3 are shown as well as the mean of the 3 reps.

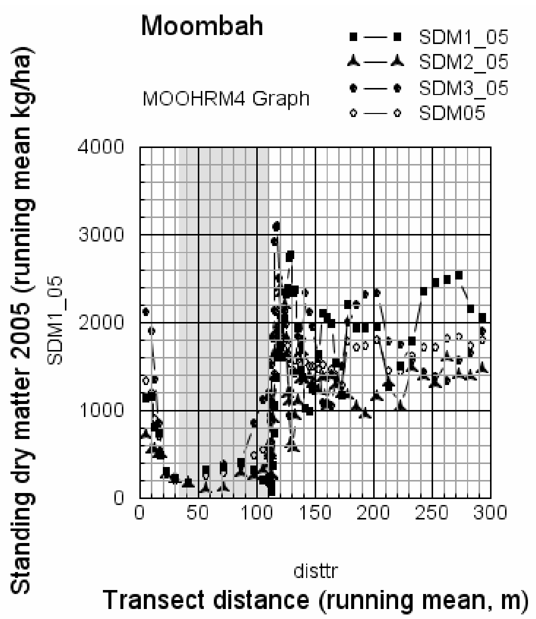


Figure 4.2.11a.

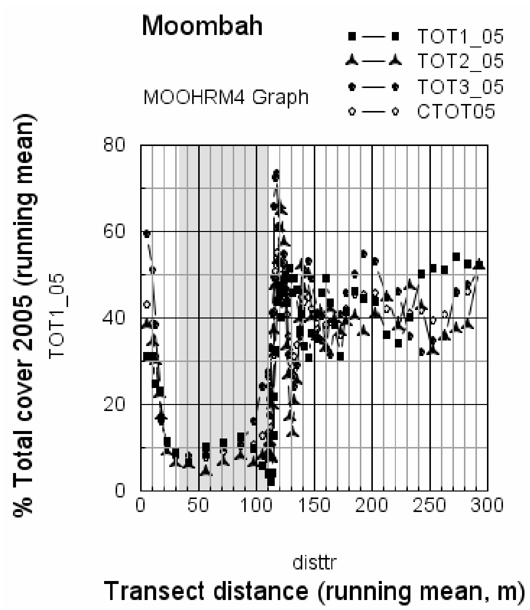


Figure 4.2.11b.

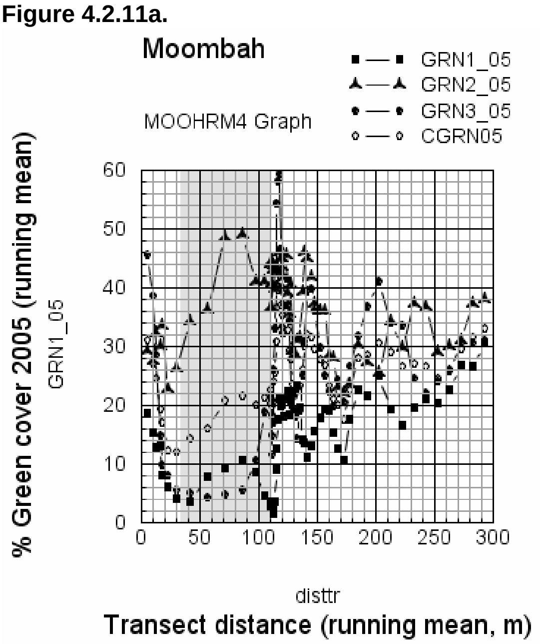


Figure 4.2.11c.

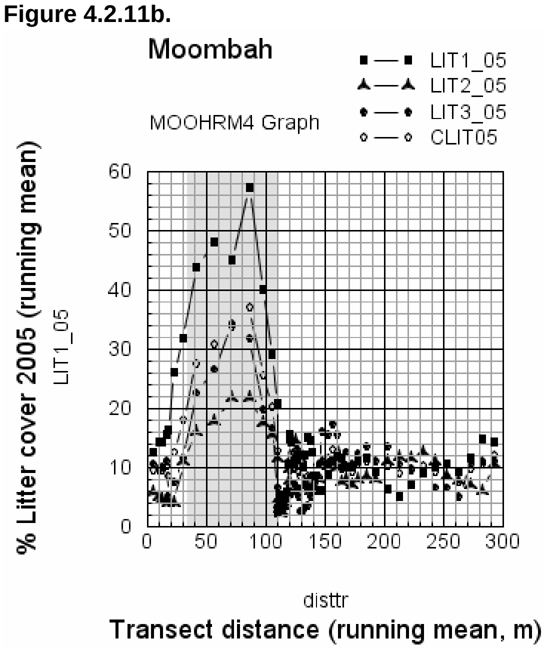


Figure 4.2.11d.

Figure 4.2.11. The relationship between transect distance (running mean) and standing dry matter (SDM), total cover (TOT), green cover (GRN) and litter cover (LIT) for 2004 at Moombah. Figure (a) is standing dry matter for 2004; Figure (b) is total cover for 2004; Figure (c) is green cover for 2004; Figure (d) is litter cover for 2004. Replicates 1, 2 and 3 are shown as well as the mean of the 3 reps.

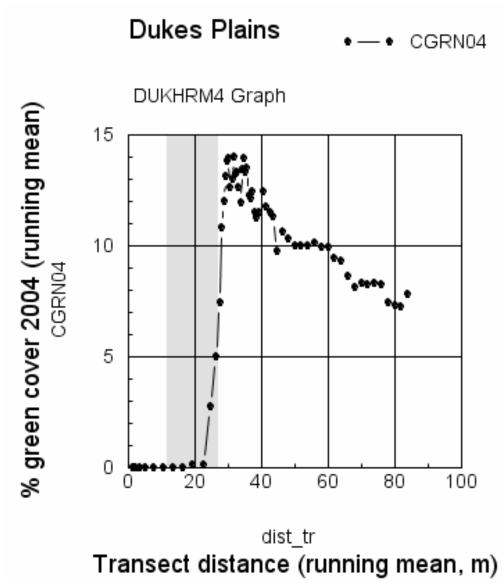


Figure 4.2.12a.

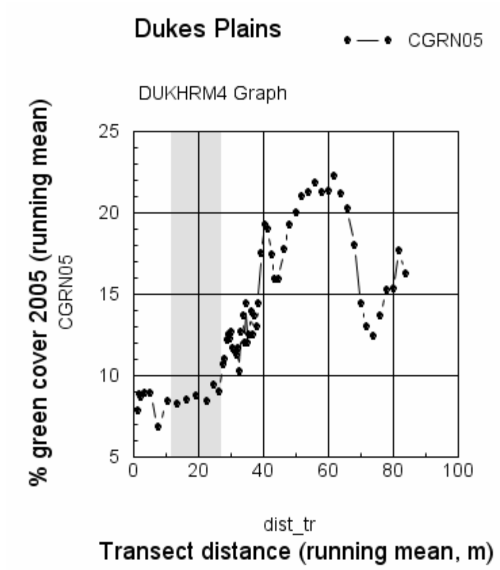


Figure 4.2.12b.

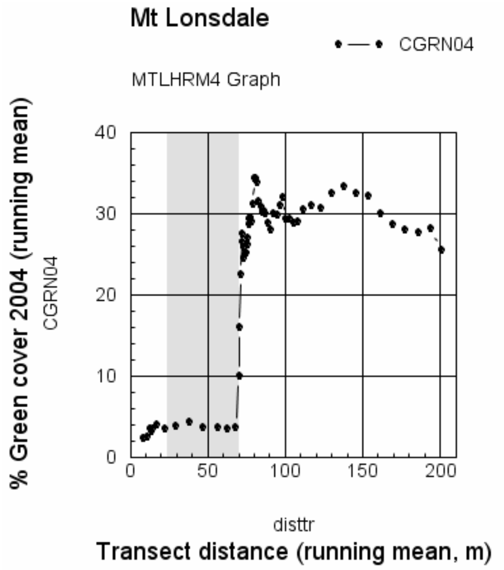


Figure 4.2.12c.

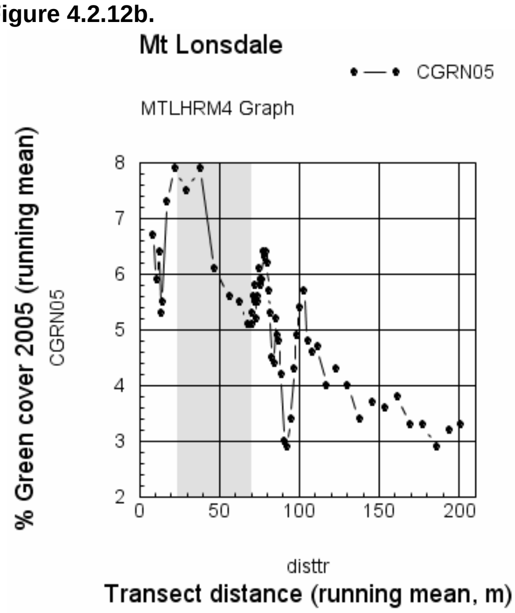


Figure 4.2.12d.

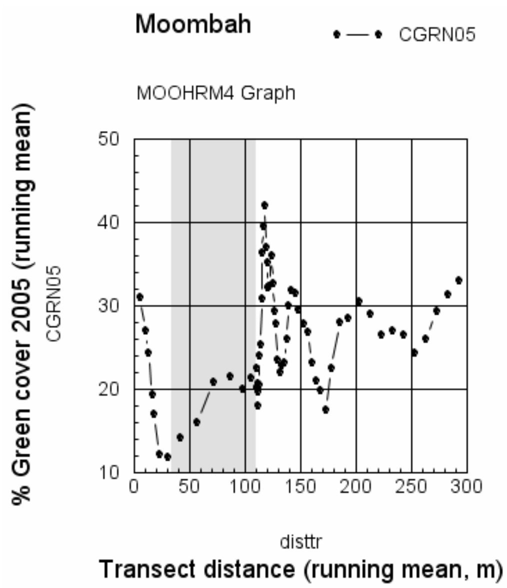


Figure 4.2.12e.

Figure 4.2.12. The relationship between transect distance (running mean) and green cover for Duke's Plain for 2004 (a) and 2005 (b); Mt Lonsdale for 2004 (c) and 2005 (d); and Moombah for 2005 (e).

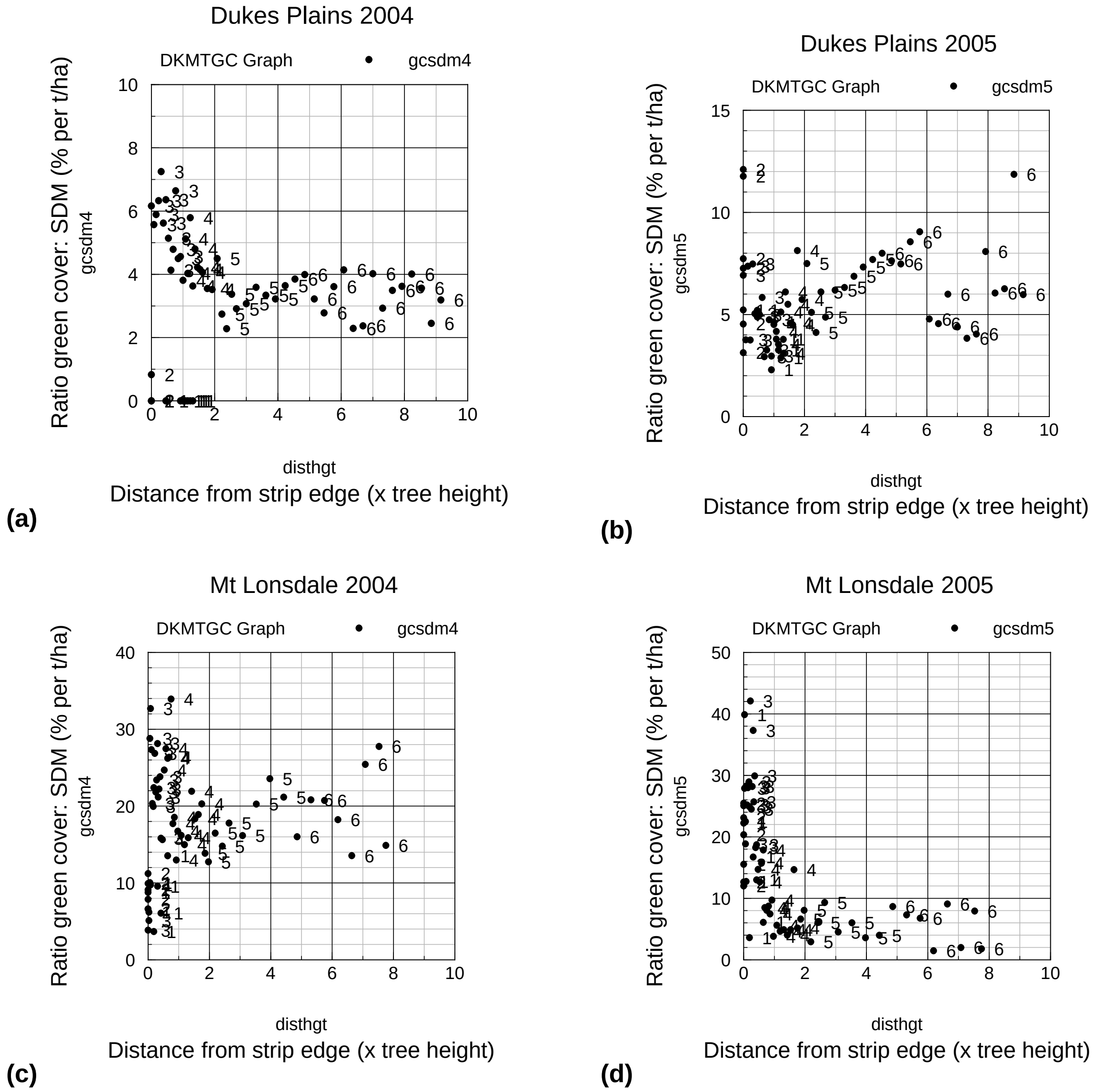


Figure 4.2.13. The relationship between distance from tree strip (x tree height) and the ratio of % green cover to pasture standing dry matter (SDM expressed as *t*/ha). The zone number is indicated for each quadrat distance (mean of 3 tree strips). Values for Zone 2 are plotted at zero distance.

4.2.3.5 Tree and shrub species composition

Duke's Plain

Duke's Plain tree strips were classified as a closed extremely tall shrubland with an estimated height of 6.5m. The strips were dominated by brigalow (*Acacia harpophylla*), and a range of other shrub species such as false sandalwood (*Eremophila mitchellii*), scrub holly (*Herterodendrum oelifolium*) and native olive (*Notoleae microcarpa*), that occurred in dense thickets scattered throughout the strips (Table 4.2.7). The site had an average tree basal area of 15.0 ± 2.9 m^2ha^{-1}, with 2085.6 ± 1028.0 stems ha^{-1}, with Replicate 2 having almost twice the density of stems and basal area than the other two replicates (Table 4.2.8). The projected foliage cover was 53.2 ± 4.2%, with a majority of that being green leaf or stem (96.2%) (Table 4.2.9).

Mt Lonsdale

Mt Lonsdale Replicates 1 and 3 were classified as woodlands, while replicate had a parkland appearance and was classified as open woodland. All replicates had an estimated height of 18m. The Mt Lonsdale replicates were all dominated by Popular Box (*Eucalyptus populnea*), with a sparse occurrence of bendee (*Acacia catenulata*) and ironwood (*Acacia excelsa*) (Table 4.2.7). The average tree basal area of the site was 16.9 ± 10.1, with 175.0 ± 144.6 stems ha^{-1}. The large variation in the site data reflects the different stand densities between the parkland appearance of Replicate 2 and the denser woodland appearance of Replicates 1 and 3. Replicates 1 and 3 had the same density of stems, but Replicate 3 had almost twice the tree basal area, reflecting the larger diameter individuals relative to Replicate 1. No trees were recorded along the sampling transect of Replicate 2, reflecting the sparse nature of the stand (Table 4.2.8). The average projected foliage cover of the site was 35.3 ± 9.7%, although Replicate 2 was less than half of both Replicates 1 and 3 (Table 4.2.9).

Moombah

At Moombah the replicates were classified as woodlands, dominated by Wilga (*Geijera parviflora*), False Sandlewood (*Eremophila mitchellii*), White cypress (*Callitris glaucophylla*) and *Dodonea viscosa*, with several late maturity tall (≥ 20 m) poplar box trees emerging from the canopy (Table 4.2.7). While classified as poplar box woodlands through the regional ecosystem mapping, the most dominant species by densities were the shrubs, not poplar box. The height of the strips was at 20 m emerging poplar box, although the height of the dominant shrub layer was between 8 to 12 m. The site had an average tree basal area of 14.9 ± 1.7 m^2ha^{-1}, with 1191.7 ± 144.6 stems ha^{-1}.

Between sites, Duke's Plain had the highest density of stems, the smallest trees and highest projected foliage cover reflecting the regrowth state of the strips. Whereas Mt Lonsdale (Replicates 1 and 3) had a open woodland structure, and Moombah was an open woodland with an high density of regenerating shrub species such as false sandlewood and wilga.

Table 4.2.7. Stem density of trees and shrubs within tree strips (Zone 2) at each site.

		Density (stems ha^{-1})		
	Species name	**Rep 1**	**Rep 2**	**Rep 3**
Duke's Plain				
	Eremophila mitchellii	1500	50	150
	Acacia harpophylla	833	1875	300
	Herterodendrum oelifolium	467	300	0
	Santalum lanceolatum	67	0	0
	Notoleae microcarpa	100	0	0
	Lysiphyllum carronii	0	250	0
	Cassia spp.	0	0	25
	Owenia acidula	0	0	75
	Breynia oblongifolia	0	0	150
	Dodonea viscosa	0	0	25
	Total	2967	4500	950
Mt Lonsdale				
	Eucalyptus populnea	250	0	225
	Acacia excelsa	0	0	25
	Acacia catenulata	0	0	25
	Total	250	0	275
Moombah				
	Geijera parviflora	225	300	150
	Callitris glaucophylla	700	0	225
	Eremophila mitchellii	125	725	175
	Eucalyptus populnea	75	75	50
	Dodonea viscosa	300	75	150
	Cassia spp.	25	0	0
	Apophyllum anomalum	0	0	200
	Total	1450	1175	950

Table 4.2.8. Tree Basal area (at 30cm above ground level) for all trees and shrubs per site and replicate. A - Mt Lonsdale values need to be re-measured.

	Tree basal area (m^2ha^{-1})		
	Rep 1	**Rep 2**	**Rep 3**
Duke's Plain	10.8	20.6	13.6
Mt Lonsdale	A	A	A
Moombah	16.5	11.5	16.7

Table 4.2.9. Projected foliage cover and proportion of green and dead per site and replicate.

		Projected Foliage Canopy Cover		
		Rep 1	Rep 2	Rep 3
Duke's Plain				
	Total	59	55	45
	%green	97	96	96
	%dead	3	4	4
Mt Lonsdale				
	Total	43	16	47
	%green	81	100	100
	%dead	19	0	0
Moombah				
	Total	43	50	33
	%green	86	92	91
	%dead	14	8	9

4.3 Soil texture, pasture and soil nutrient status, microbial activity and biomass and soil mesofauna

4.3.1 Introduction

Tree strips and associated clearing practices are likely to influence nutrient inputs, soil environment, and associated soil mesofauna along the pasture transect.

Measurements were taken of soil properties (% carbon and nitrogen), pasture nutrient uptake and concentration (nitrogen and phosphorus). Soil mesofauna provide a useful indicator of soil ‘health’ in terms of nutrient availability and water infiltration.

The soil chemical analysis is yet to be fully analysed and only preliminary results are presented

4.3.2 Methods

Soil Texture

Soil particle size distribution was measured at one replicate (same replicate as soil moisture) at each location. The texture classes are presented as clay, silt, fine sand and coarse sand. The depths sampled were 0-10cm and 10-30cm. The measurements were taken at the same replicate as used for soil moisture measurements, namely Replicate 2 at Duke’s Plain, Replicate 1 at Mt Lonsdale and Replicate 1 at Moombah.

PSA and Nutrient sampling

Air-dried soils were passed through 2mm sieve to remove roots and rocks, and ground (<2mm) for particle size analysis (PSA) and fine ground (0.5mm) for organic carbon and nitrogen analysis. Disaggregation and dispersion of soil samples permitted determination of the distribution of coarse and fine sand gravimetrically, and silt and clay soil particles by a hydrometer (NRSL 2002a). The size ranges were defined as coarse (0.2-2.0mm) and fine (0.02-0.2mm) sand, silt (0.002-0.02mm) and clay (<0.002mm).

Soil nutrient status

Samples for nitrogen were taken at 2 depth classes of 0-10cm and 10-30cm (from the mineral soil surface). Samples were taken only in the ungrazed treatments across all three replications at each site. 30 samples along a transect sampling scheme (60m long with a sample every 2m on alternate sides of the tape) were taken across both depth classes and bulked for each zone, approx 1kg of soil was sub-sampled from the bulked sample.

Soils were prepared according to grinding requirements for each test and passed through a 2mm sieve. Soils were subsampled and sent for analysis on soil carbon, total nitrogen, plant available phosphorous, soil pH and electrical conductivity and particle size analysis. Soil carbon content was analysed using the Walkley and Black method using H_2SO_4 and carbon content being measured colorimetrically. Total nitrogen was determined using the Kjeldahl digestion method and extractable phosphorus using the Colwell extraction using $NaHCO_3$ and measured colorimetrically. Bulk density (g/cm^3) for each bulked sample was also determined.

Soil pH was be measured in a $CaCl_2$ in a 1:5 suspension and read using a combination electrode.

Pasture nitrogen and phosphorus content and yield
Four dry matter yield samples from each zone in the intensive harvest survey were randomly selected for nitrogen and phosphorus analysis. The herbage materials were bulked, and ground (<2mm) prior to sub-sampling. The total nitrogen and phosphorus (expressed as a percentage) were determined using the CNS-2000 Leco instrument (NRSL 2002b) following dry combustion at 1300^{o}C of samples in purified oxygen stream.

Soil mesofauna
Six soil cores of 10cm in diameter to 7.5cm depth were taken from each zone (2 samples per replicate). The samples were placed is sealed polyethylene storage bags and transferred to containers with ice bricks for transport to the Department of Natural Resources & Mines Laboratory located in Toowoomba. Samples were then placed immediately into funnels for invertebrate extraction. None of the samples were stored or in transport for more than 24 hours.

Simple tullgren funnels (Murphy, 1962) were used to extract mesofouna from the soil core. This consists of a plastic funnel overlain by a light and heat lamp with a collection tube underneath containing ethanol that catches the fauna as they burrow through the soil away from the light and heat (Moldenke, 1994, 523). The samples were kept under lights for 7 days in an inverted position. After seven days all samples were sealed and refrigerated for sorting and counting.

Collembola were identified to Family, and mites to Order according to the classification of Evans *et al*. (1961). The four main Orders were Cryptostigmata, Mesostigmata, Prostigmata, and Astigmata. All other invertebrates were identified to Order.

4.3.3 Results

Soil particle size analysis
Figure 4.3.1 shows particle size distribution across a replicate at each site for 0-10cm and 10-30cm depths. The soil at the three locations range from a high portion of clay content (Duke's Plain) to high (fine) sand content (Moombah). Duke's Plain and Moombah were relatively uniform along the transect (i.e. across zones). At Mt Lonsdale Rep1, there was a clear gradient from high (coarse) content of sand in Zones 1 to 3, to high content of clay in Zones 5 and 6. Thus, the change in soil type at Mt Lonsdale along the transect in Rep1 (and possibly Rep3) are likely to be reflected in other measurements of soil fertility, soil water (Section 4.4) and pasture response (Section 4.2).

Soil carbon and nitrogen
Figure 4.3.2 shows % soil total carbon and % soil total nitrogen. Although interpretation at this stage is limited without correction for bulk density, nevertheless the measurements suggest that at Duke's Plain, under mainly brigalow trees, there was higher carbon and nitrogen concentration. At Mt Lonsdale, the trend in increasing % soil nitrogen along the transect away from the tree strip reflects the trend in soil texture (increasing clay content, Figure 4.3.1) measured at one replicate (#1).

At this stage of data analysis it is not clear whether other differences measured across zones and locations are significant. There are a wide range of possible outcomes (increased/decrease/no change) on soil carbon and nitrogen associated with clearing of woody vegetation and subsequent grazing that have been measured in other studies (J. Carter personal communication). Further analysis of this important data set is warranted to determine influence of clearing and grazing on carbon and nitrogen cycles.

Pasture nutrient uptake and nutrient concentration

Nutrient uptake and nutrient concentration (Figure 4.3.3 and 4.3.4) were estimated for each zone from measurements of pasture standing dry matter, and nitrogen and phosphorus concentrations in May 2005 at the end of the growing season (Table 4.3.1). Rainfall was below average in 2005 with soil water frequently limiting. Hence nutrient yields in Table 4.3.1 cannot be regarded as expressions of potential nutrient uptake that would be expected to occur with greater soil water supply. In addition, measurements at the end of the growing season are likely to include the effects of losses in nutrients through detachment and translocation and hence are likely to underestimate potential nutrient uptake. Nutrient concentrations in unfertilised situations, such as the pastures in this study, decline through the growing season until the minimum nutrient concentration required for growth is reached. The capacity of pastures to dilute available nutrients thus determines peak dry matter production. The reciprocal of nutrient concentration represents ‘nutrient use efficiency’. The zones with lowest nutrient concentrations (i.e. highest nutrient use efficiencies) are indicated in Table 4.3.1.

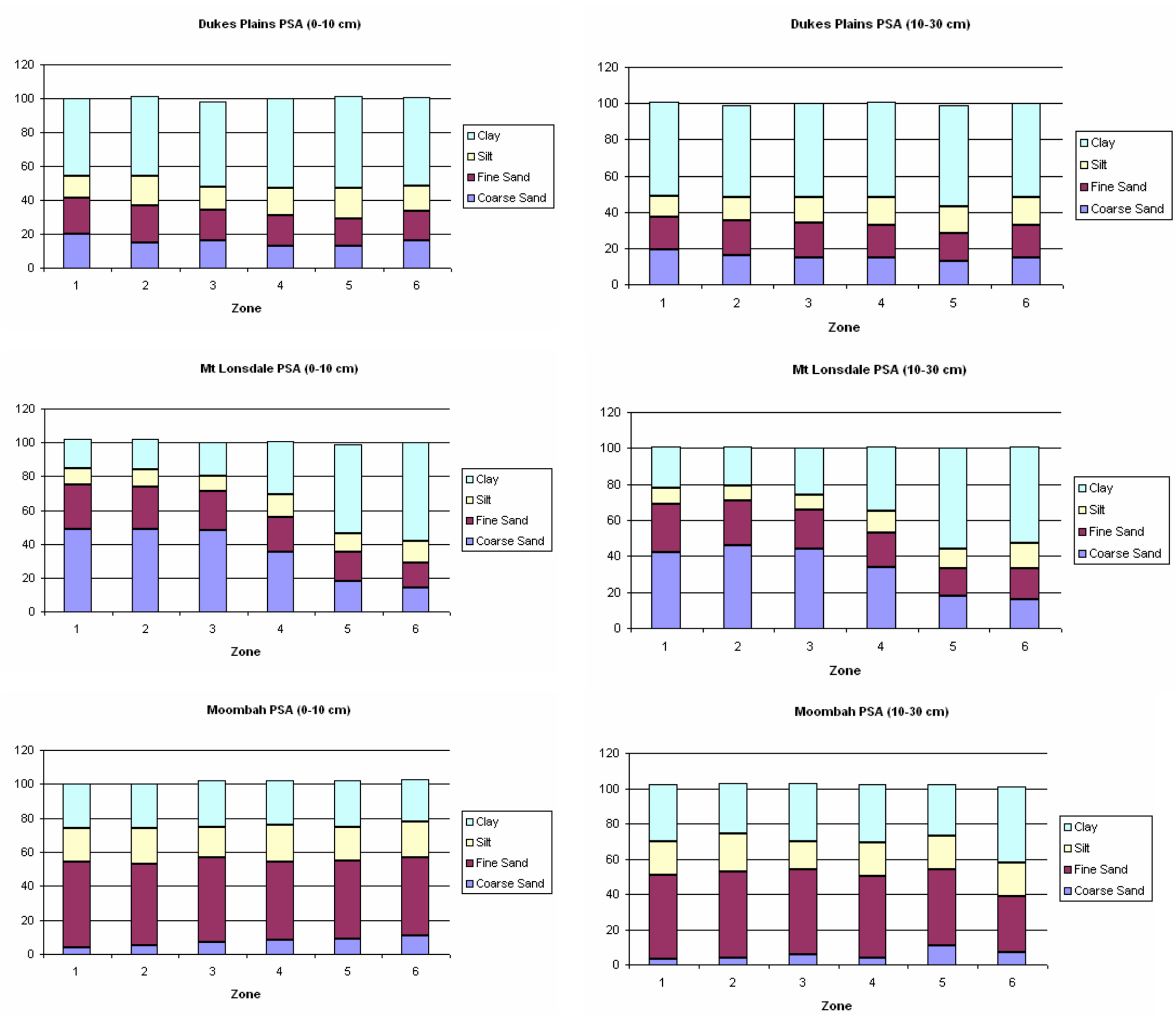


Figure 4.3.1. Soil particle size distribution measured at depths 0-10cm and 10-30cm at one replicate at each location. The same replicate was used as for soil moisture measurements, namely Replicate 2 at Duke's Plain, Replicate 1 at Mt Lonsdale and Replicate 1 at Moombah.

Overall, pasture nutrient yields (N and P) were lower inside the tree strip (Zone 2) than the peak yields in the pasture transect (Zones 3 to 6) reflecting the lower pasture dry matter in Zone 2 resulting from tree competition. Nutrient concentrations were not generally higher in Zone 2 and were generally comparable to adjacent Zones 1 and 3 indicating similar dilution of nutrients across the range of growing environments along the pasture transect.

For nitrogen yield at Duke's Plain, Zone 3 had the highest uptake (21 kgN/ha) with relatively little difference across other pasture zones (17-19 kgN/ha; Zones 4, 5 and 6). The fact that at Duke's Plain the highest nitrogen yield value occurred in Zone 3, was in contrast to the measurement at Mt Lonsdale and Moombah, and may reflect the possible nitrogen fixing capability of brigalow trees at Duke's Plain. Nitrogen concentrations were lowest in Zone 4 at Duke's Plain indicating greater dilution of available nitrogen due to favourable growing conditions.

At Mt Lonsdale, nitrogen yields were low (<7.5 kgN/ha) because of the unfavourable growing season with concentrations declining away from the tree strip. At Moombah Zones 4, 5 and 6 had higher nitrogen yields than other locations despite the low rainfall at this site. These nutrient yields reflect the higher inherent fertility of the site, a view that is supported by the fact that grain cropping was the normally expected land use following clearing.

In terms of modelling (Section 4.7), the above results from Duke's Plain have been used as a base to parameterise the effects of tree strips on the potential dilution of available nitrogen. The results from Mt Lonsdale at the end of the drier season of 2004/05 have been also used to investigate tree strip effects (Section 4.7) under conditions when nutrients are not likely to be limiting pasture growth.

Soil mesofauna

Figures 4.3.5, 4.3.6 and 4.3.7 show the number of soil invertebrates measured for zone x location combination. The greatest number of soil invertebrates were recorded in Zone 2 at all sites. At Duke's Plain, over 56,100 ± 6580 were recorded in Zone 2. At Mt Lonsdale there were 62,600 ± 5,300 beneath trees, while Moombah had fewer total numbers, 36,200 ± 4700, but followed the same trend. The Acari dominated the populations accounting for approximately 83% of the population in all zones at Duke's Plain, with Collembola accounting for 12%, and the remaining 5% others. At Mt Lonsdale the Acari accounting for more than 90% of the soil invertebrate populations in Zone 2 and 6, but only about 75% of the population in Zones 3 and 4. At Moombah, the Acari were also the dominant group, accounting for over 90% of the population in Zone 2, but this was reduced to approximately 70% of the population in all other Zones. The collembolan made up a majority of the remaining proportion, with all other invertebrate Orders rarely accounting for more than 55.

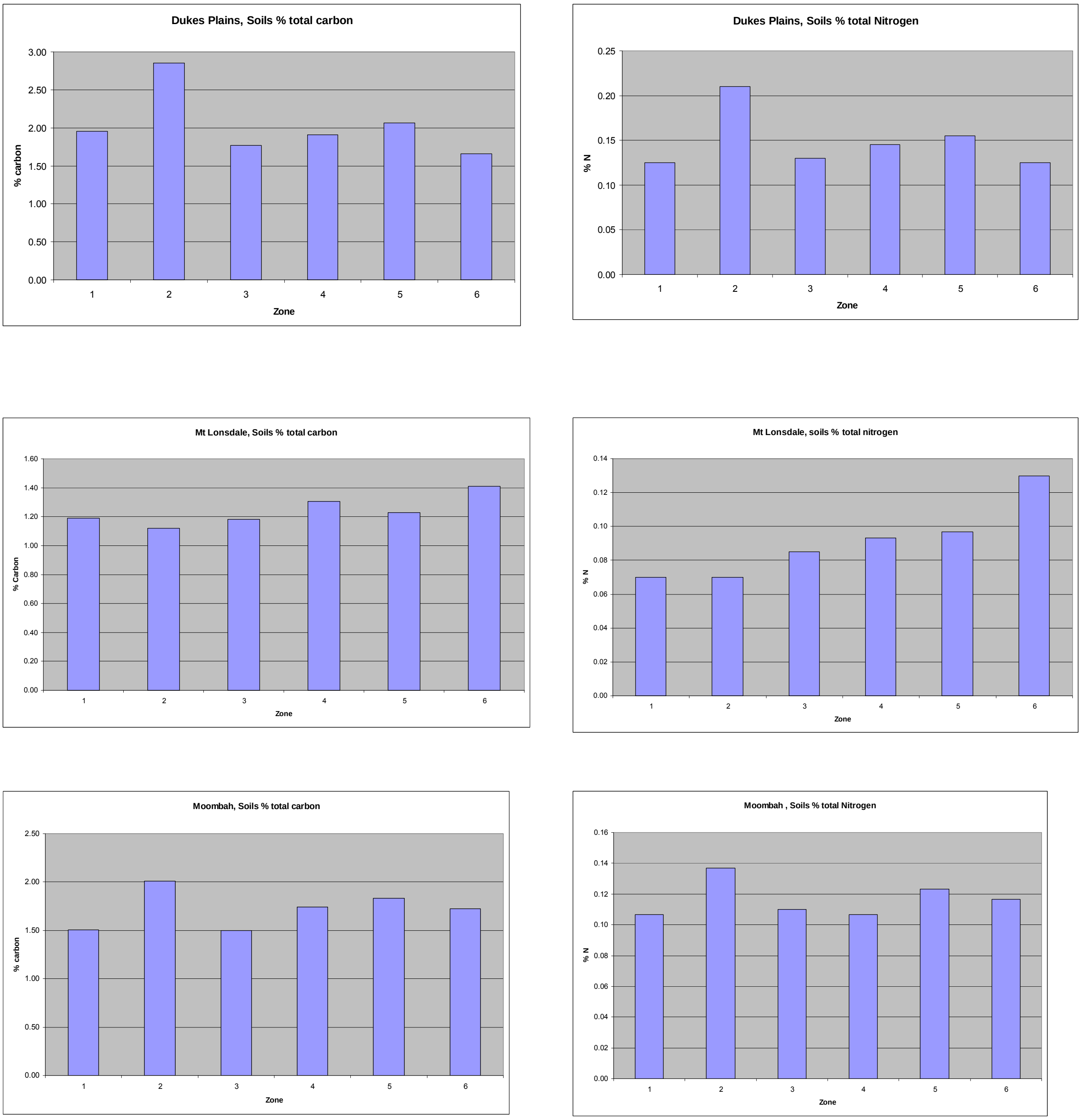


Figure 4.3.2. Measurement of soil carbon and nitrogen along the pasture transect for Duke's Plain, Mt Lonsdale and Moombah. Sampled soil depth was 10cm. Data have not been corrected for bulk density.

Table 4.3.1. Nitrogen and phosphorus concentrations and yields at Duke's Plain, Mt Lonsdale and Moombah measured in May 2005. The low values at Mt Lonsdale are the result of a dry year and low pasture growth. [A] indicates zone with minimum nutrient concentration for Zones 2 to 6 and [B] indicates zones with maximum nutrient yield.

Zone	% N Concentration			N Yield (kgN/ha)		
	Duke's Plain	Mt Lonsdale	Moombah	Duke's Plain	Mt Lonsdale	Moombah
1	0.62	1.13	1.68	14.7	7.5	15.9
2	1.02	0.92	1.18 [A]	12.5	3.9	3.1
3	0.90	0.91	1.35	21.4 [B]	2.1	13.1
4	0.54 [A]	0.69	1.36	17.0	3.5	22.7
5	0.58	0.68	1.36	18.5	5.5 [B]	20.0
6	0.70	0.67 [A]	1.45	18.8	3.8	23.9 [B]
Zone	**% P Concentration**			**P Yield (kgN/ha)**		
	Duke's Plain	**Mt Lonsdale**	**Moombah**	**Duke's Plain**	**Mt Lonsdale**	**Moombah**
1	0.14	0.09	0.09	3.23	0.58	0.92
2	0.17	0.09	0.05 [A]	2.02	0.36	0.14
3	0.16	0.09	0.06	3.75	0.20	0.63
4	0.15	0.07	0.08	4.74 [B]	0.35	1.28 [B]
5	0.15	0.07	0.08	4.65	0.53 [B]	1.18
6	0.14 [A]	0.06 [A]	0.09	3.67	0.34	1.50

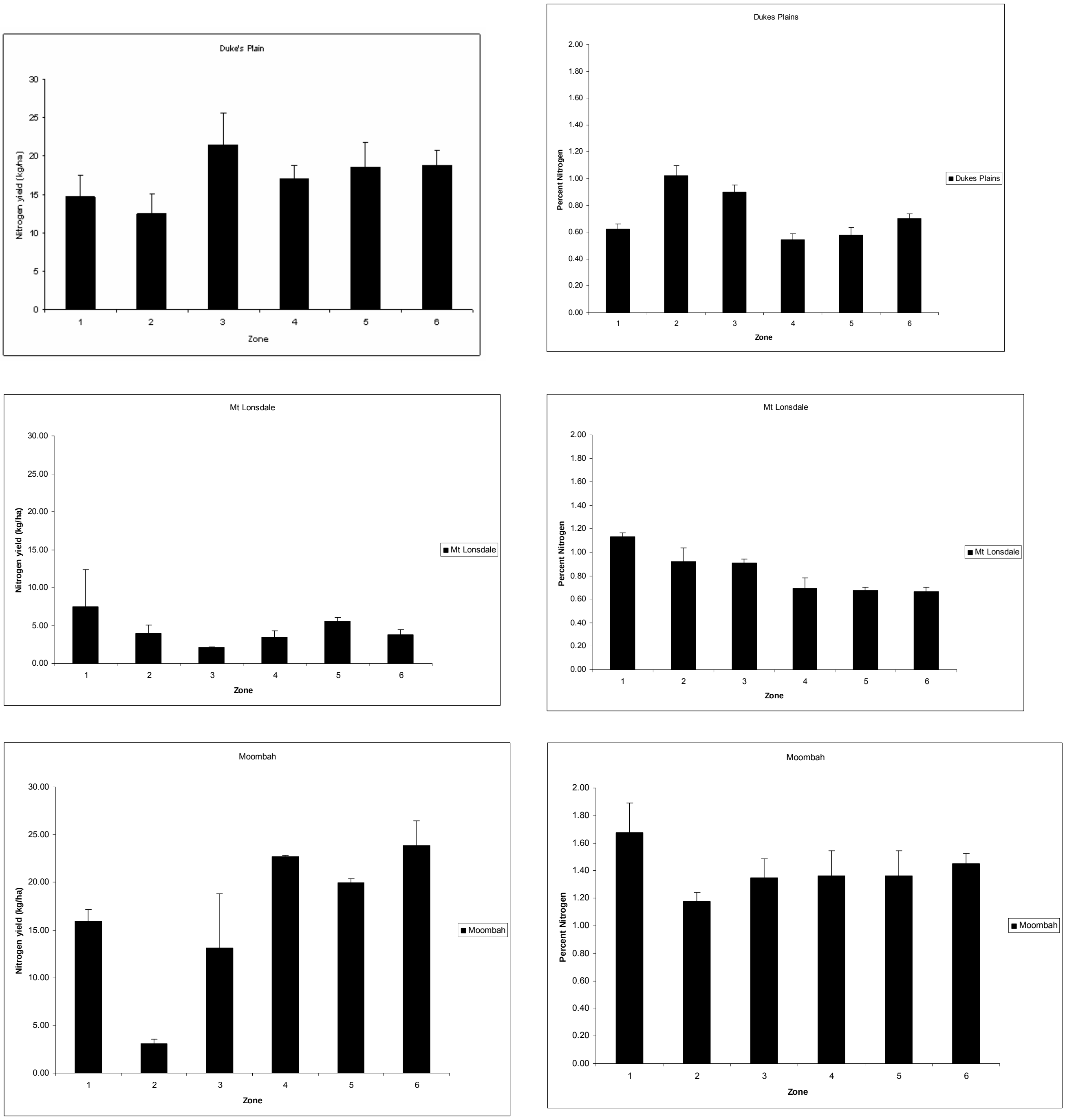


Figure 4.3.3. For May 2005, nitrogen yields and concentrations across zones for Duke's Plain, Mt Lonsdale and Moombah. Nitrogen yield values at Mt Lonsdale are low because of low rainfall in 2004/2005. Pasture exclosures were mown in winter 2004.

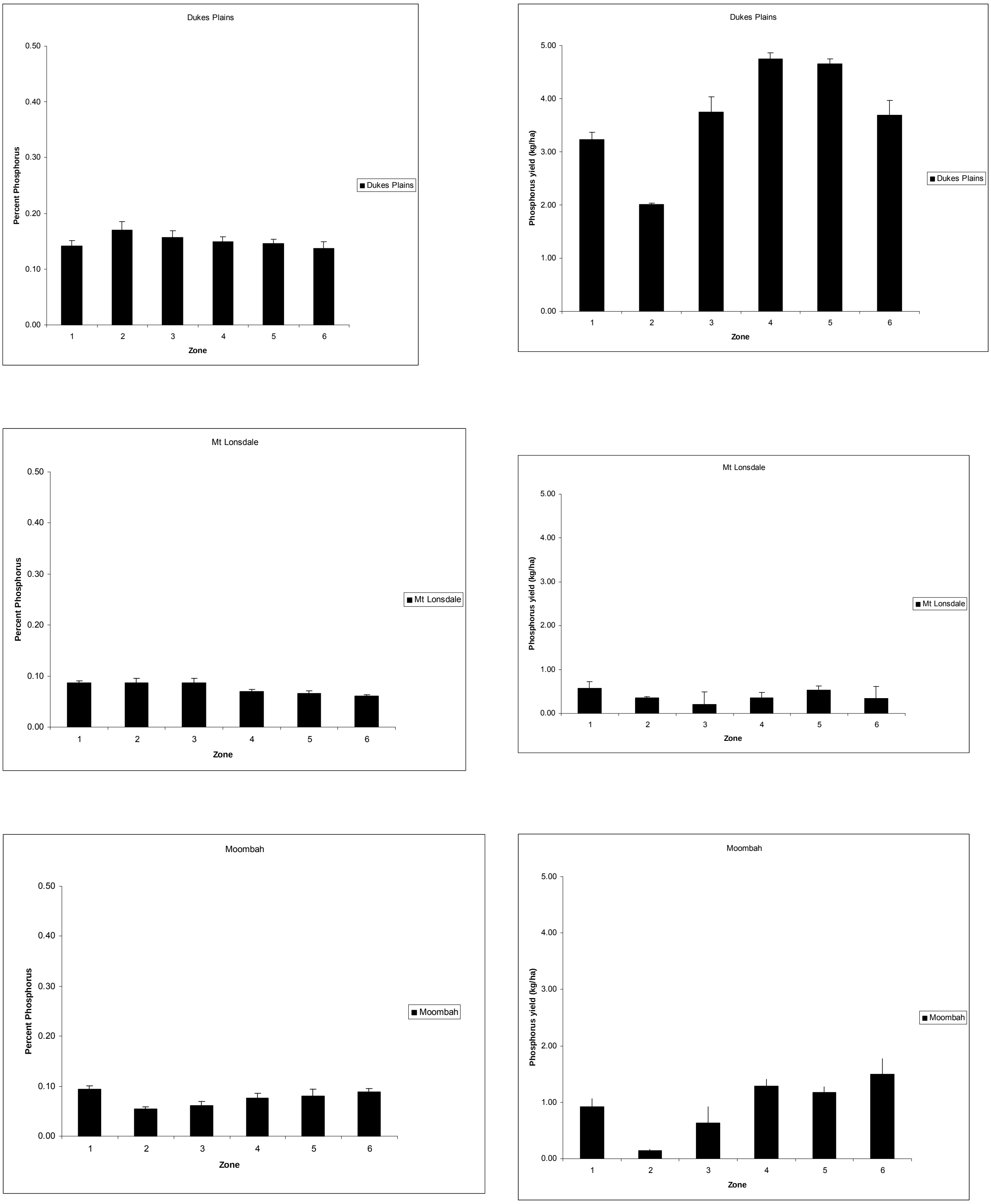


Figure 4.3.4. For May 2005, phosphorus yields and concentrations across zones for Duke's Plain, Mt Lonsdale and Moombah. Phosphorus yield values at Mt Lonsdale are low because of low rainfall in 2004/2005. Pasture exclosures were mown in winter 2004.

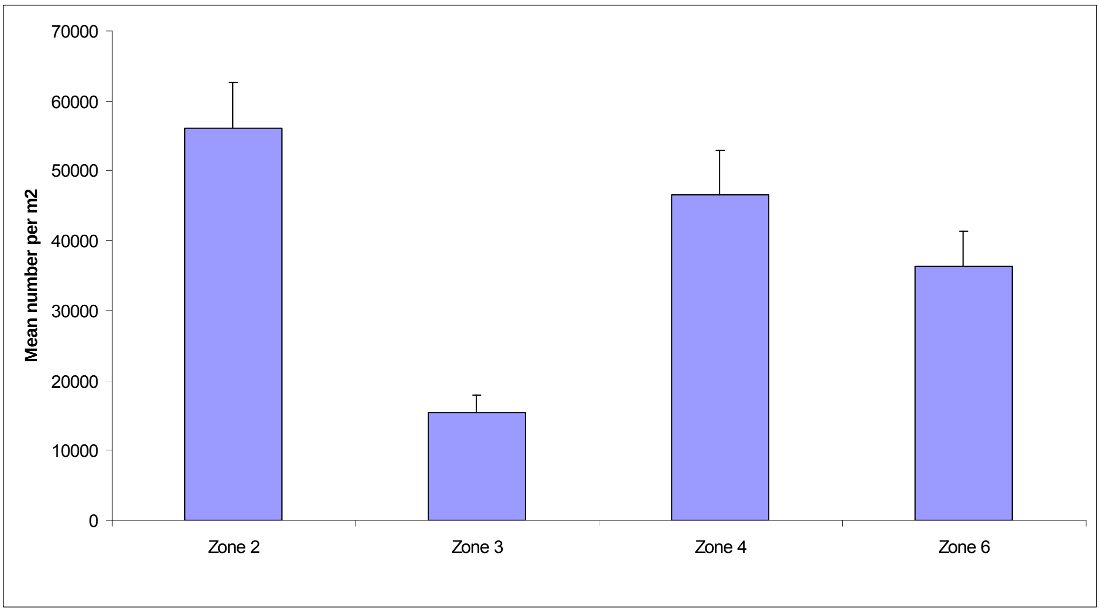


Figure 4.3.5. Mean number of soil invertebrates collected at Duke's Plain. The bars are standard errors of the mean.

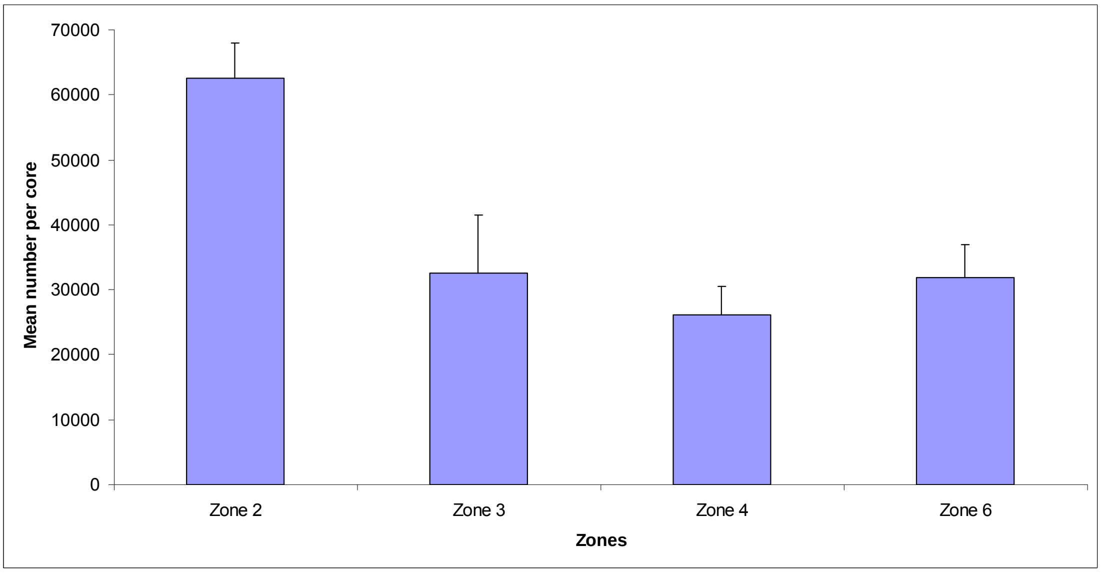


Figure 4.3.6. Mean number of soil invertebrates collected at Mt Lonsdale. The bars are standard errors of the mean.

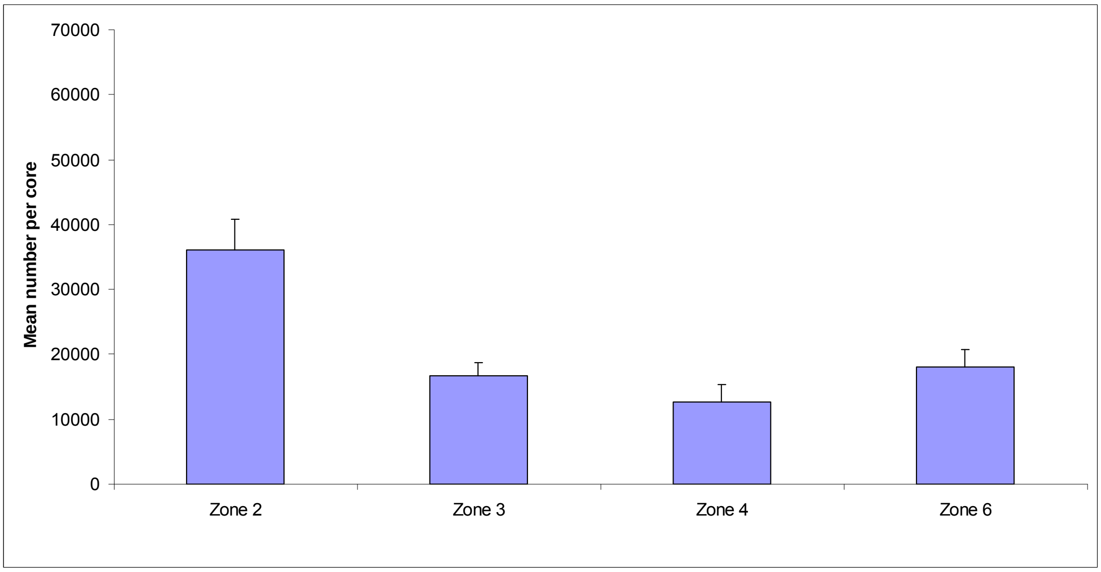


Figure 4.3.7. Mean number of soil invertebrates collected at Moombah. The bars are standard errors of the mean.

4.3.4 Conclusion

Preliminary analyses of soil chemistry, pasture nutrient uptake and soil mesofauna indicated zones of possible benefit in terms of soil nutrition and 'health'. However, the analysis is not complete and a more detailed analyses of transect variability is required to further identify zones where trees are exerting influence relative to effects of soil variability and those of post-clearing management.

4.4 Soil water measurement

4.4.1 Introduction

In the sub-humid climates of southern Queensland, rainfall occurs throughout the year with a dominance in summer (November to March) supporting warm-season growing pastures. As a consequence trees and pasture compete strongly during the growing season for soil moisture. Rainfall episodes in which deeper layers of soil are recharged are not frequent. Thus, available soil water for evapo-transpiration is mainly stored in the upper layers and hence the competition between trees and grass for soil water is mainly in the upper soil layers (0-50cm of soil). Recharge of deeper soil layers (>50cm) is mainly dependent on: (1) the influence of surface cover, infiltration attributes and rainfall intensity; and (2) how much water is stored above wilting point in the upper layers (i.e. soil water deficit). When the soil water deficit of the upper layers is high due to use by pastures and trees, then most of the rainfall that infiltrates will be stored in the upper soil layers. Thus, the measurement of soil moisture at different layers in the soil across the tree-pasture transect provides an indication of the extent of tree and pasture root activity and the likely frequency of recharge of deeper soil layers. Comparison of measurements under exclosure (ungrazed) and grazed pastures provides data showing how grazing and tree strip influences interact.

The following sections describe the measurement of soil moisture at different zones along the tree-pasture transect and at three depths (15cm, 40cm and 80cm). Measurements at 15cm represent soil moisture in the main evapo-transpiration zone, measurements at 40cm are the main rooting zone for both trees and pastures, and measurements at the 80cm zone provide indications of the frequency of recharge in the zone where rooting densities of pasture and trees are likely to be lower compared to the surface. The distance of sites along the pasture transect used for soil moisture measurements are summarised in Table 4.4.1.

The following description represents the initial analysis of the data. It is incomplete in terms of description of rainfall events, lack of on-site rainfall, description of bulk density measurement, and issues of sensor calibration. A major limitation in interpreting the soil moisture data is that rainfall was not measured at the field sites. The possible role of microtopography and timber debris in terms of runoff/run-on redistribution is yet to be assessed. Detailed evaluation of soil texture profiles to determine matric potential characteristics, and evaluation of data with soil water balance models are yet to be done.

A major issue in preparing this report was that the principal field investigators (C. Chilcott and W. McGrath) were not available to provide detailed descriptions of field procedures and data analysis. Given the constraints of time in completing this report, these issues will be reported at a later date.

4.4.2 Methods

Intermittent soil moisture measurements across zones were taken at Duke's Plain (January 2004 to April 2005) and Mt Lonsdale (November 2003 to November 2005). The instruments measuring soil water were located in their various positions. The instruments used were supplied by Campbell Scientific and were a combination of

CS615 and CS 616 water content reflectometers.

They were installed at 15cm, 45cm and 80cm in a horizontal position to detect the passing of wetting fronts. Where installation was difficult the probe was moved up or down the profile slightly. One probe was installed at each depth in a hole excavated using a dingo mini digger down to a depth of approx 1 metre. The probes were inserted using a pilot tool and a drilling guide. The plot tool consisted of a cordless drill and a threaded bit approx 5ml shorter than the probe length. The drilling guide consisted of a section of steel approx 5cm wide with holes drilled in it to guide the drill bit and ensure that the probes were inserted as close to parallel as possible. In most soils the soil structure would be expected to recover from the disturbance during probe installation (Campbell Scientific 2002, p4).

The probes were installed in the centre of each zone on one replicate at each of the three main sites within the ungrazed enclosure. In addition probes were placed at an equivalent distance from the trees in the grazed treatment. These probes were located approximately 10 meters into the grazed treatment to avoid compaction issue with cattle trampling. There was no vehicle traffic within proximity to these probes during the life of the project. The exact distance and location of the probes are given in Figures 4.1.1 to 4.1.3. Output from the probes were collected on Campbell Scientific 10x dataloggers and downloaded periodically.

The water content reflectometer consists of two stainless steel rods connected to a printed circuit board. A shielded four-conductor cable is connected to the circuit board to supply power, enable the probe, and monitor the pulse output. The circuit board is encapsulated in epoxy. (Campbell Scientific 2002, p1)

High-speed electronic components on the circuit board are configured as a bistable multivibrator. The output of the multivibrator is connected to the probe rods which act as a wave guide. The travel time of the signal on the probe rods depends on the dielectric permittivity of the material surrounding the rods and the dialectic permittivity depends on the water content. Therefore, the oscillation frequency of the multivibrator is dependant on the water content of the media being measured. Digital circuitry scales the multivibrator output to an appropriate frequency for measurement with a datalogger (Campbell Scientific 2002, 1). A calibration equation converts periodic to volumetric water content and these were derived for each of the sites.

To be certain of the accuracy of soil moisture measurements recorded by the datalogger, the Campbell Scientific reflectometer manual recommends that the datalogger measurements be calibrated against a number of manually measured soil moisture contents throughout the range of wet through to dry soil conditions. In particular the manual recommends individual sensor calibration when measurements are being undertaken in soils with high clay content or soils with a high salt content. However little sensor calibration was undertaken due to the resources and time required to operate the separate locations.

It was very difficult to sample for bulk density at Duke's Plain and Mt Lonsdale. Soils were very dry at installation at Mt Lonsdale. At Duke's Plain, although wetter, the profile remained cracked and a solid core could not be obtained to depth. At Duke's Plain, the calibration of soil moisture was based on profile values measured at the time of installation (mid March 2004). At Mt Lonsdale, the calibration was based on sampling at two times to cover a range of moisture conditions: 16 January 2004 (wet) and 10 August 2005 (dry). At Duke's Plain, bulk density was only able to be measured at the surface 0-10cm. Values (g/cc) for Zones 1 to 6 were 1.22, 1.21, 1.22, 1.10, 1.24 and 1.21 respectively. At Mt Lonsdale, a pit was dug and samples taken at 15, 35 and 80cm (1.45, 1.50 and 1.55 g/cc respectively).

4.4.3 Results

Duke's Plain
The procedure for analysing the data was to compare soil water measured at the greatest distance from the tree strip (Zone 6) with measurements at other zones. For example, the comparisons of Duke's Plain are based on a major rainfall event that occurred in February 2004 providing high soil moisture to 80cm in Zone 6 and a subsequent dry down to the end of continuous daily measurement in October 2004. Given the intermittent nature of the soil moisture measurements, only a limited analysis in comparing zones can be attempted. A more comprehensive analysis will require the use of soil water models. However, high quality rainfall data required for such an analysis are not available. Measurements at ungrazed sites at Duke's Plain are shown for each of thee three depths in Figures 4.4.1.2 and 4.4.1.3 and for grazed sites in Figures 4.4.4.5 and 4.4.4.6. The measurement of long time-series of daily soil water values in the field at remote locations is a difficult task. Thus, the comparison of Zone 6 with other zones is necessarily based on those days when measurements were available at each zone being compared. Comparisons of grazed and ungrazed soil moisture are given in Figures 4.4.7 to 4.4.9. The analysis has been repeated for Mt Lonsdale (Figures 4.4.10 to 4.4.19). The time series of soil moisture measurements for each layer are shown in Figures 4.4.19 to 4.4.24.

Duke's Plain exclosed (ungrazed) and grazed sites
As indicated above soil moisture values for Zone 6 at Duke's Plain are dominated by a single rainfall event in 2004 and subsequent dry down over the next 8 months. In the case of the February 2004 event, measurement in Zones 2, 3 and 4 did not commence until March 2004. Nevertheless, Zone 6 still had high soil moisture at this time. Figures 4.4.1 and 4.4.4 show the comparison between Zone 6 and other zones at 15cm depth for exclosed (ungrazed) and grazed sites respectively. Across all zones (1, 2, 3 and 4), soil moisture was generally lower than Zone 6 under both wet and dry conditions. In the case of Zone 4, dry values approached those values measured at Zone 6, whilst at the other zones, driest values were 20% lower (20%) than Zone 6. Similar differences under dry conditions occurred in the comparison of zones measured under grazing (Figure 4.4.4), although there was less difference between Zone 6 and in Zones 3 and 4. At wetter soil moisture values, the difference between the zones and Zone 6 was less for grazed sites than for ungrazed sites. Thus, the soil moisture measurements for the surface suggest that the influence of the tree strip across the tree-pasture transect is reduced by Zone 4 (1-2 x tree height).

Figures 4.4.2 and 4.4.5 show the comparison between Zone 6 and the other zones at 40cm depth for ungrazed and grazed sites respectively. For ungrazed sites, the wettest and driest values were similar for each zone. For grazed sites, wetter values were measured for Zones 1, 2 and 3 compared to Zone 6 suggesting reduced evapo-transpiration and/or root activity under grazing.

Figures 4.4.3 and 4.4.6 show the comparison between Zone 6 and the other zones at 80cm depth for ungrazed and grazed sites respectively. Both ungrazed and grazed sites showed that Zones 1-4 remained dry through a wet episode in which soil moisture at 80cm in Zone 6 was recharged and dried out. Several reasons could be hypothesised for this lack of recharge, including greater runoff and/or greater soil water deficit prior to the wet episode in Zones 1-4. The measurements indicate that the influence of trees on soil water extends to Zone 4. However, the driest values measured in all zones were similar, even under the tree strip, indicating that the lowest available soil moisture value was similar for zones dominated either by trees (Zone 2) or pastures (Zone 6).

Figures 4.4.7., 4.4.8 and 4.4.9 show the comparison between ungrazed and grazed sites for each zone and soil depth. Grazed sites had higher soil moisture zones and soil depths in 7 out of 15 combinations of zone and depth, and similar values in five of the combinations. Important exceptions are Zone 3 at 40cm depth (Figure 4.4.8C) and Zone 2 at 80cm depth (Figure 4.4.9B) when there were periods that the grazed sites had substantially lower soil moisture. Higher soil moisture values for grazed pastures were likely to reflect that reduced evapo-transpiration and root activity had occurred under grazing. An important feature of the grazed sites (Zones 1 and 2) was that there were days with substantially wetter values at 15cm and 40cm depth. In these zones, the values at 15cm declined more rapidly than the surface values in Zone 6 declined, suggesting greater rates of evapo-transpiration and/or drainage to deeper layers. Further analysis with models will be required to separate these processes.

Mt Lonsdale

Mt Lonsdale exclosed (ungrazed) and grazed sites

Figures 4.4.10, 4.4.11 and 4.4.12 and Figures 4.4.13, 4.4.14 and 4.4.15 show the comparison between Zone 6 and the other zones for ungrazed and grazed sites respectively. At Mt Lonsdale measurements were carried out at all six zones. The comparison of soil moisture measured in Zones 1 to 3 with Zone 6 involves soil profiles of different texture, namely high content of coarse sand in Zones 1 to 3 and high clay content in Zones 5 and 6. Thus, the range in soil moisture (i.e. wettest to driest) is more likely to reflect texture effects rather than the effect of trees (Figure 4.3.1).

Soil moistures at 15cm (Figures 4.4.10A, B, C and 4.4.13A, B, C, Zones 1-3) were substantially less than Zone 6 (under pasture furthest from tree strip) under dry and wet conditions. In contrast, Zones 4 and 5 (Figures 4.4.10D, E and 4.4.13D, E) had a similar range in soil moisture to Zone 6.

Figures 4.4.11 and 4.4.14 show the comparison between Zone 6 and the other zones at 40cm depth for ungrazed and grazed sites respectively. As at 15cm, there were substantially lower soil moistures for Zones 1-3 compared to Zone 6. Zone 4 had generally lower soil moistures, while Zone 5 had similar to Zone 6.

Figures 4.4.12 and 4.4.15 show the comparison between Zone 6 and the other zones at 80cm depth for ungrazed and grazed sites respectively. For ungrazed sites, values for Zones 1-3 were substantially lower than for Zone 6, whilst values for Zones 4 and 5 were slightly lower or equal to those measured in Zone 6. For grazed sites, Zones 1-4 had substantially lower values than Zone 6, although there was evidence that some partial recharge of these deeper layers had occurred. The results for Zone 5 are equivocal with agreement with Zone 6 occurring at wetter soil moistures but lower values occurring when driest soil moistures occurred.

Figures 4.4.16, 4.4.17 and 4.4.18 show the comparison between ungrazed and grazed sites for each zone and depth. Grazed sites were wetter than ungrazed sites for four of the 15 combinations of zone and depth and had similar soil moisture for four other combinations. Grazed sites were substantially drier than ungrazed sites for 6 of the 15 combinations of zone and depth with half of the deeper soil layers (40 and 80cm) having generally lower values under grazing. The complexity of these patterns suggests that the understanding of the interactions of runoff, evapo-transpiration, root activity will be required to interpret Mt Lonsdale soil moisture. However, the lower soil moisture values of deeper soil layers under grazing suggests less infiltration associated with lower surface cover.

4.4.4 Discussion

Soil moisture is the net result of the processes of runoff, infiltration, drainage and evapo-transpiration. Evapo-transpiration itself involves soil evaporation and grass and tree transpiration. Thus, the observed patterns of soil moisture themselves require some modelling of the different processes to estimate the varying influence of tree strips across the zones. We will report further once this modelling has been conducted. Nevertheless, with the caveat that the measurements span a limited number of rainfall events, some general conclusions can be suggested from soil moisture measurements at Duke's Plain and Mt Lonsdale.

The influence of the tree strip extended to Zone 4 (1-2 x tree height) at both locations. For example, ungrazed soil moistures measured at 80cm in Zones 1-4 were substantially lower than in Zone 6 (Figures 4.4.3 and 4.4.12). In the case of Mt Lonsdale, the influence of the tree strip on 40cm soil moisture occurred in Zones 1-3 with less influence in Zones 4 and 5. There was little influence on 40cm soil moisture across Zones 1 to 4 at Duke's Plain although the data are restricted to drier periods (Figure 4.4.5). We note that Zones 1 and 3 at Mt Lonsdale were actually closer in terms of multiples of tree heights (0.26) than the same zones at Duke's Plain (0.58, Table 4.4.1). Hence the greater effects at Mt Lonsdale may reflect that the zones were under greater influence of the tree strip. The following section (4.4.5) assesses the implications of the measurements for Mt Lonsdale in greater detail.

Table 4.4.1. Distance of sites for soil water measurement distance from nearest edge of tree strip in metres and multiples of tree height.

Zone	Duke's Plain Distance from edge		Mt Lonsdale Distance from edge		Moombah Distance from edge		
	Metres	x tree height	metres	x tree height	Metres	x tree height	
1	-3.8	-0.58	-4.8	-0.26	-4.8	-0. 40	-0.24
2	-9.3	A	-27.3	A	-45.3	A	A
3	3.8	0.58	4.8	0.26	4.8	0.40	0.24
4	9.8	1.50	20.8	1.15	24.8	2.06	1.24
5	24.8	3.81	60.8	3.38	74.8	6.23	3.74
6	50.8	7.81	136.8	7.60	194.8	16.23	9.74

[A] Middle of tree strip.

The low soil moistures in the deeper soil depth of 80cm compared to Zone 6 suggest that greater evapo-transpiration is occurring from the surface layers (<50cm) in Zones 1-4. In the case of Zones 3 and 4, there are substantially higher pasture yields and cover than in Zone 6, suggesting greater evapo-transpiration and hence greater soil water deficits in the surface layers (0-50cm). Thus the influence of the tree strip in terms of lower soil moisture may not necessarily reflect the presence of tree roots, but may in fact indicate better pasture growing conditions and greater pasture root activity in Zones 3 and 4.

Soil moisture was generally higher under grazing across the zones of influence of tree strips at Duke's Plain (Figure 4.4.7). In contrast, at Mt Lonsdale the deeper soil layers under grazing had lower soil moisture. As indicated above, modelling will be required to indicate the opposing influences that grazing has on hydrological processes, namely increasing runoff but reducing evapo-transpiration.

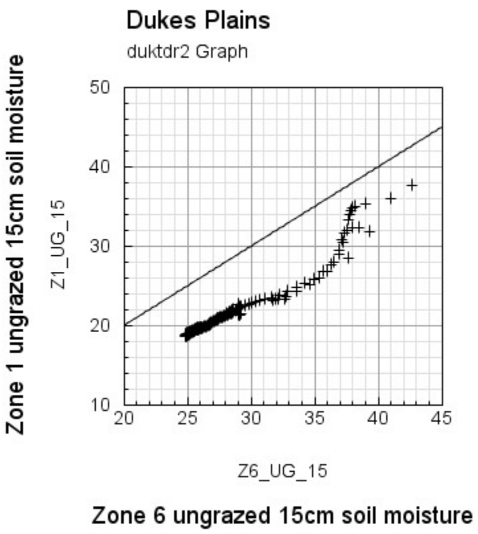


Figure 4.4.1a. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

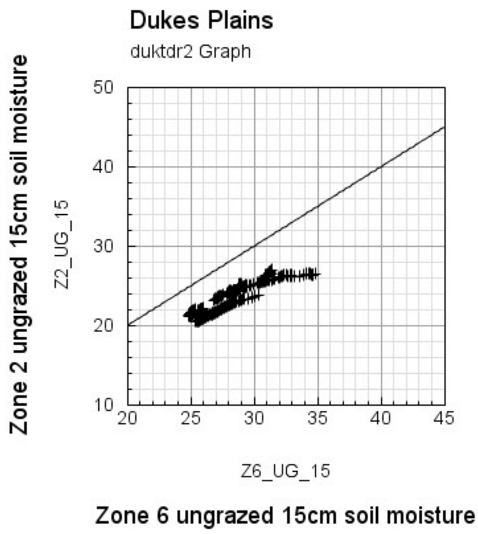


Figure 4.4.1b. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

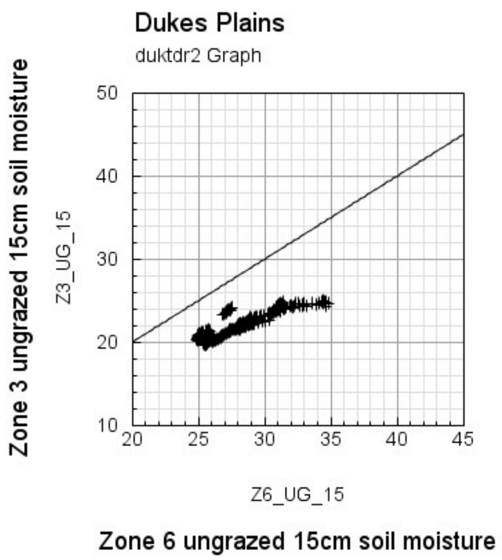


Figure 4.4.1c. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

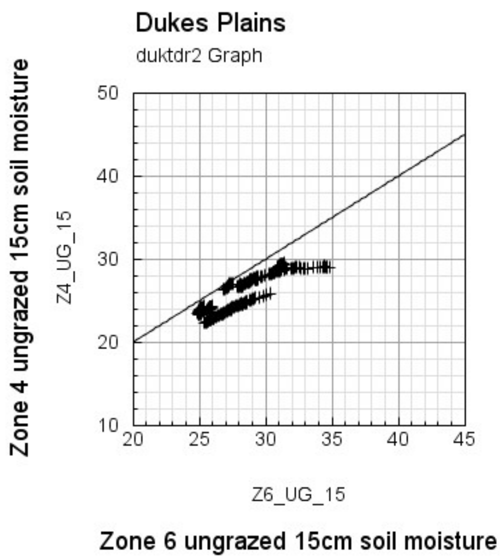


Figure 4.4.1d. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

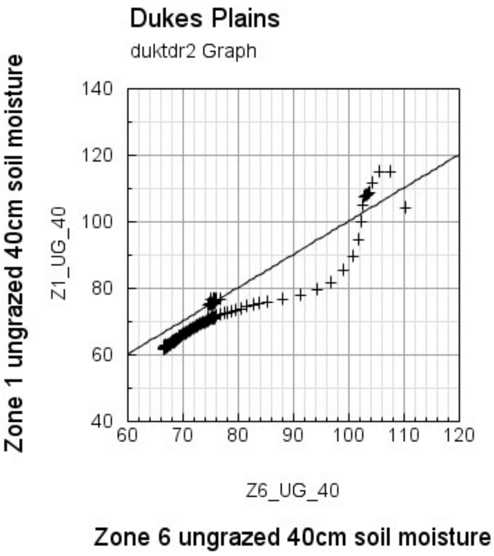


Figure 4.4.2a. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

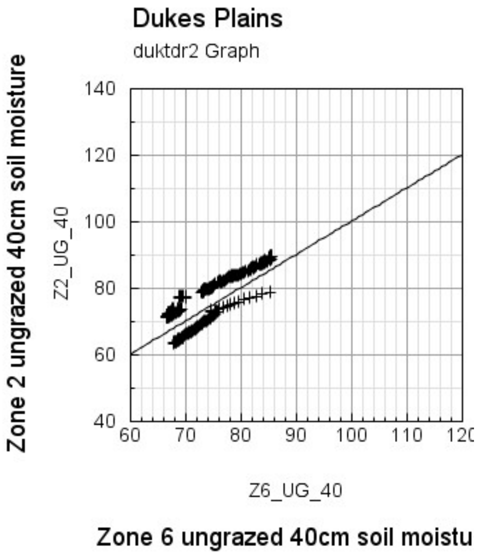


Figure 4.4.2b. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

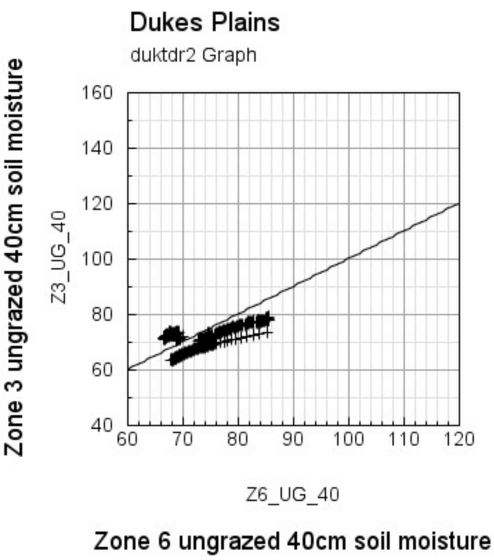


Figure 4.4.2c. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

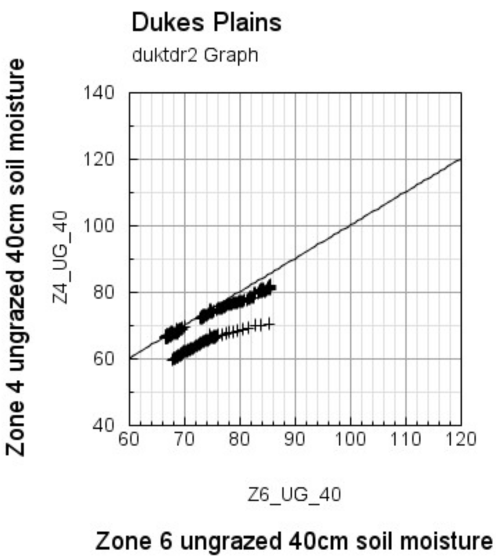


Figure 4.4.2d. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 4 (X times the tree height away from the tree strip canopy). The one-to-one line is indicated.

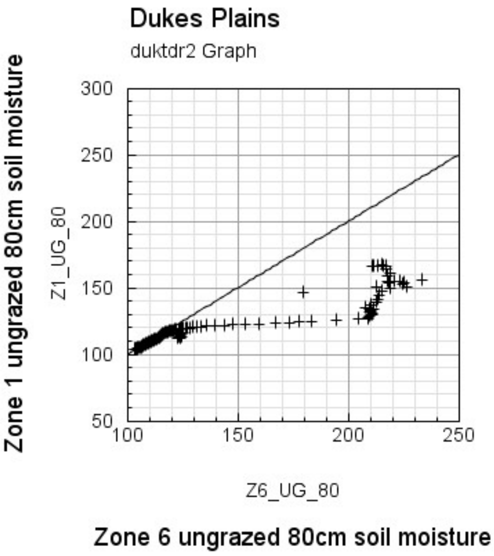


Figure 4.4.3a. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

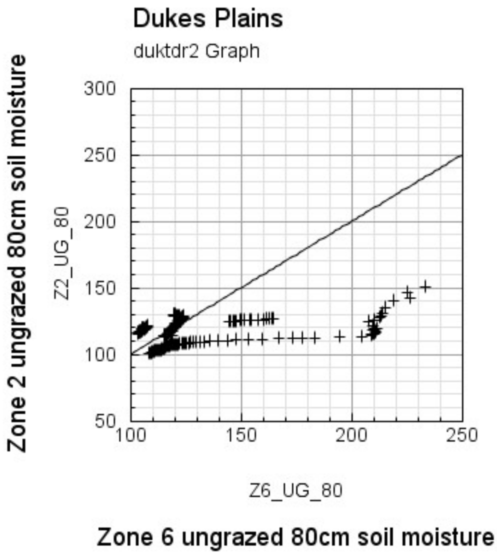


Figure 4.4.3b. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

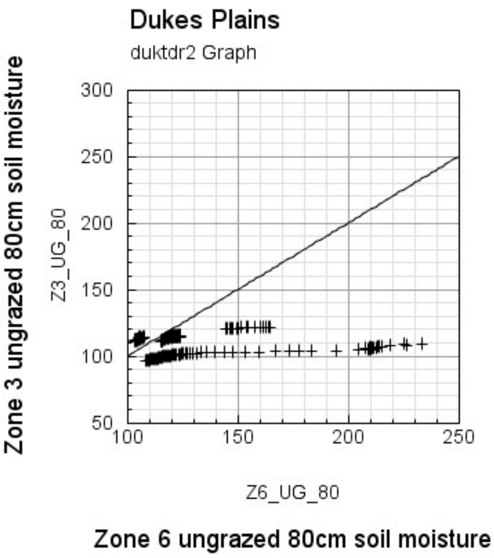


Figure 4.4.3c. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

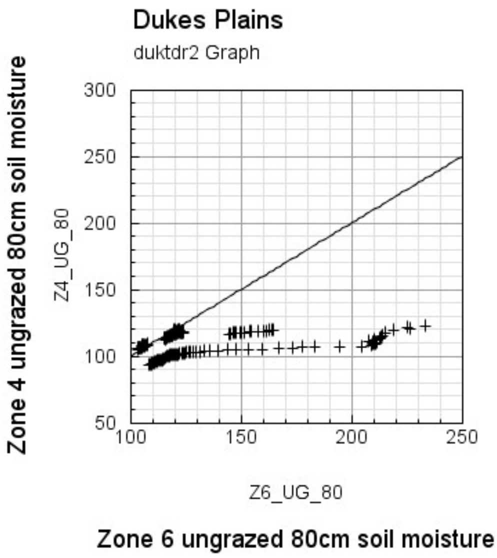


Figure 4.4.3d. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

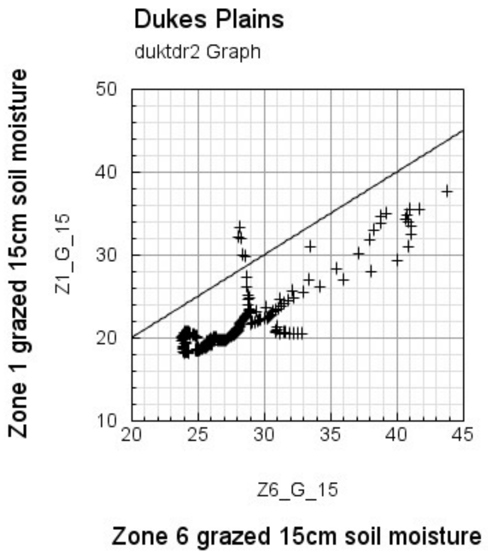


Figure 4.4.4a. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

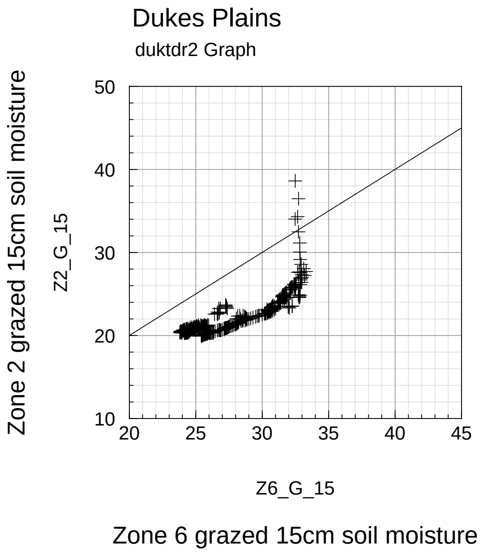


Figure 4.4.4b. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

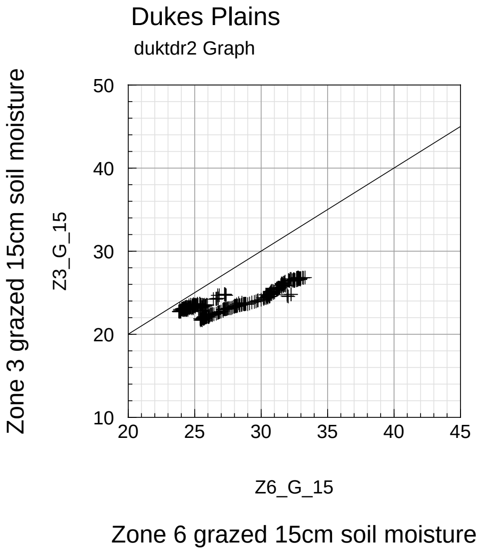


Figure 4.4.4c. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

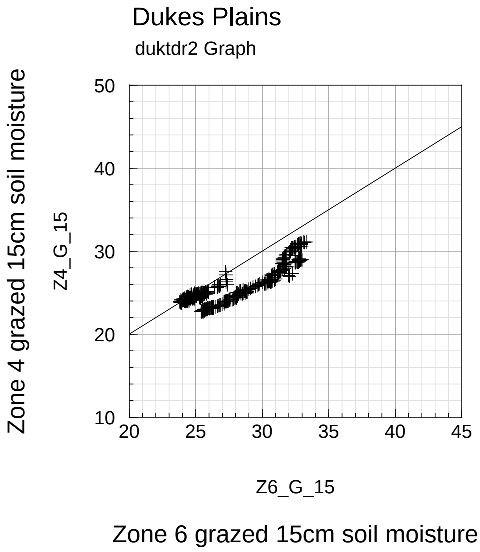


Figure 4.4.4d. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

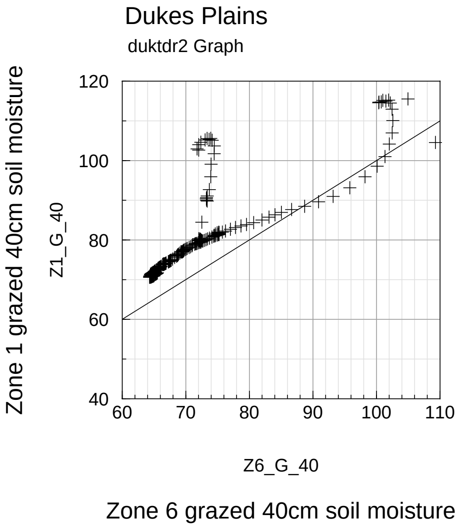


Figure 4.4.5a. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

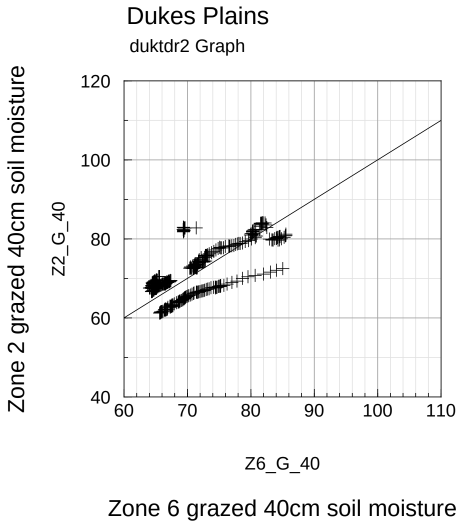


Figure 4.4.5b. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

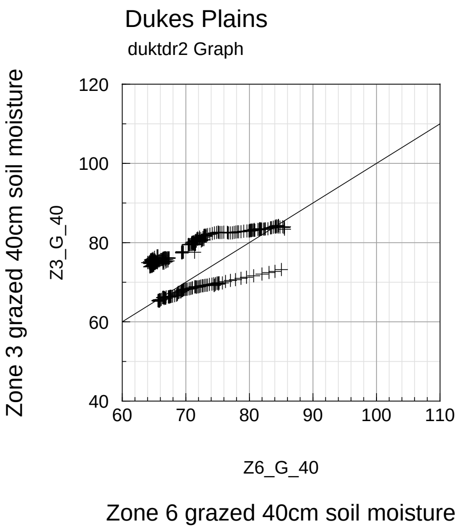


Figure 4.4.5c. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

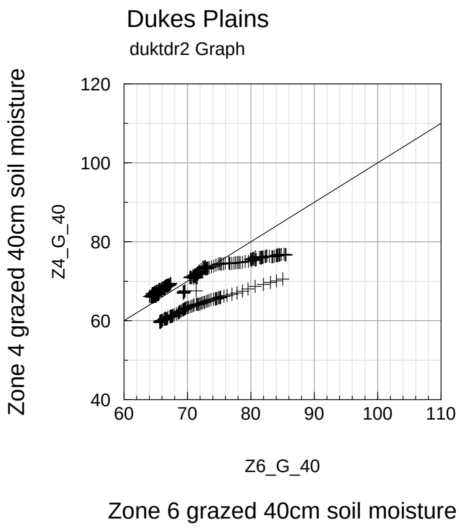


Figure 4.4.5d. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

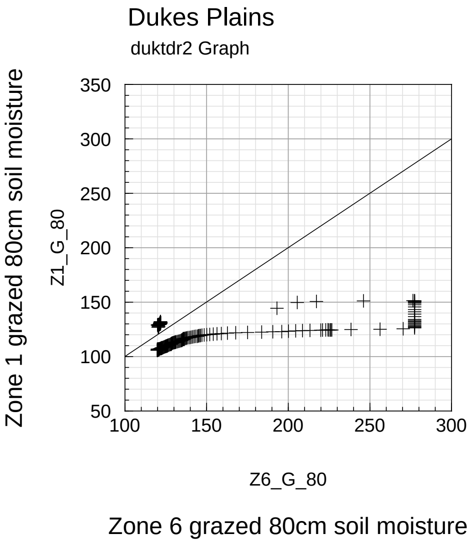


Figure 4.4.6a. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated. Over the range of soil moistures, Zone 6 (greatest distance from tree strips) had higher soil moisture values.

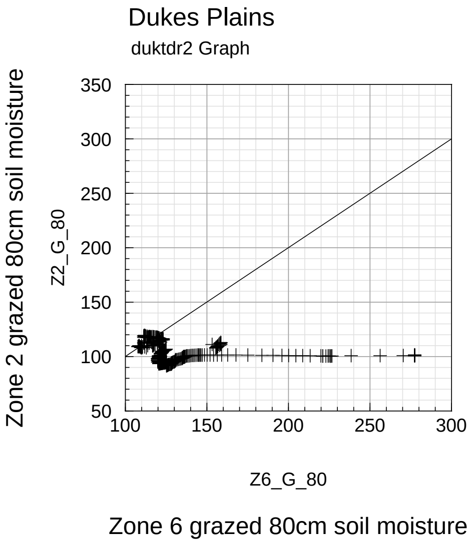


Figure 4.4.6b. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 2 (inside the tree strip). The one-to-one line is indicated. Over the range of soil moistures, Zone 6 (greatest distance from tree strips) had higher soil moisture values than under the trees.

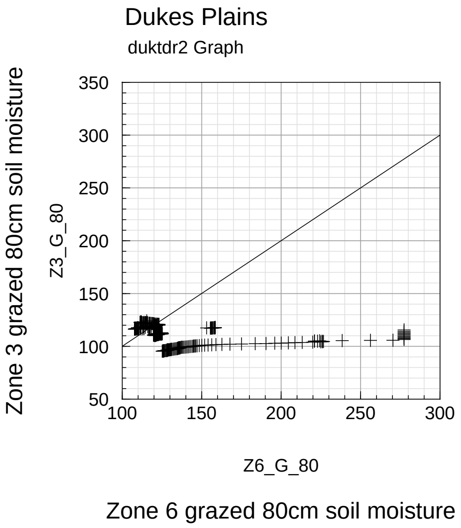


Figure 4.4.6c. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated. Over the range of soil moistures, Zone 6 (greatest distance from tree strips) had higher soil moisture values indicating the effects of trees outside the canopy.

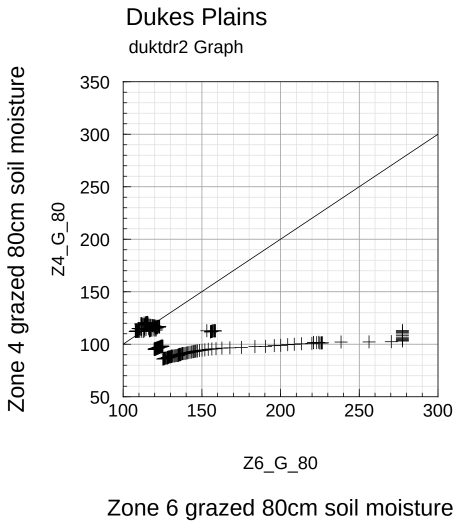


Figure 4.4.6d. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated. At low soil moistures Zone 6 had similar soil moisture, but at high soil moistures, Zone 6 had greater soil moisture values.

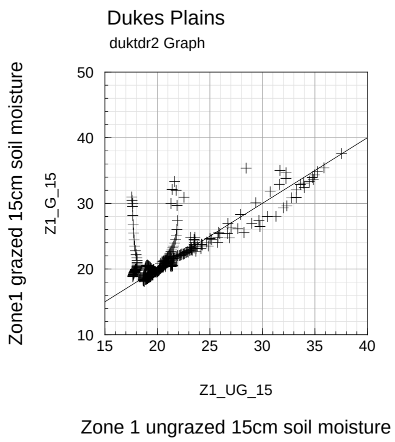


Figure 4.4.7a

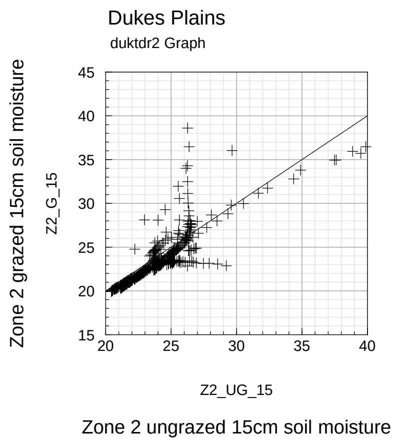


Figure 4.4.7b

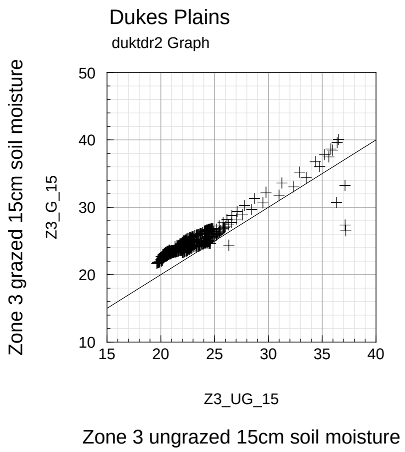


Figure 4.4.7c

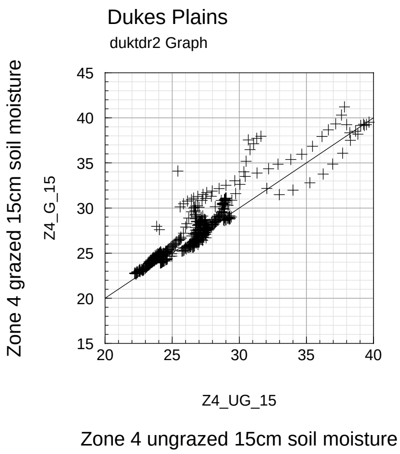


Figure 4.4.7d

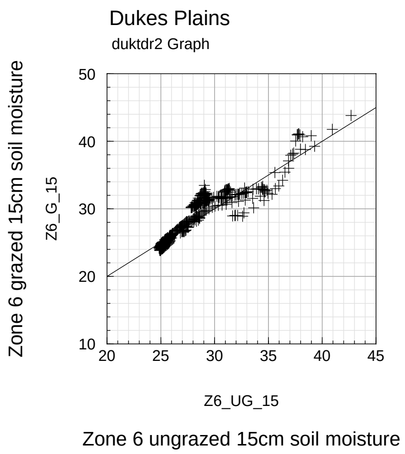


Figure 4.4.7e

Figure 4.4.7. For Duke's Plain comparison of exclosed (ungrazed) and grazed soil moisture for each zone at 15cm depth: Figure (a) Zone 1; (b) Zone 2; (c) Zone 3; (d) Zone 4 and (e) Zone 6. The one to one line is indicated.

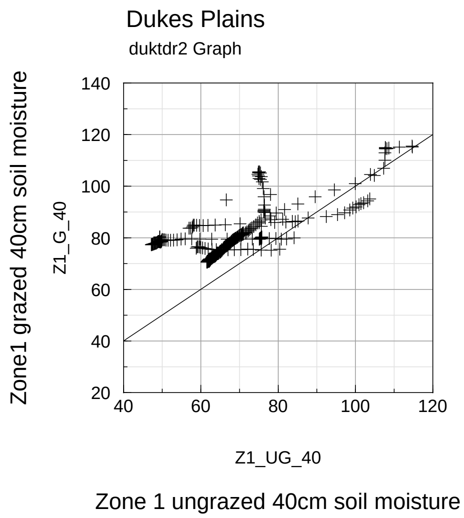


Figure 4.4.8a

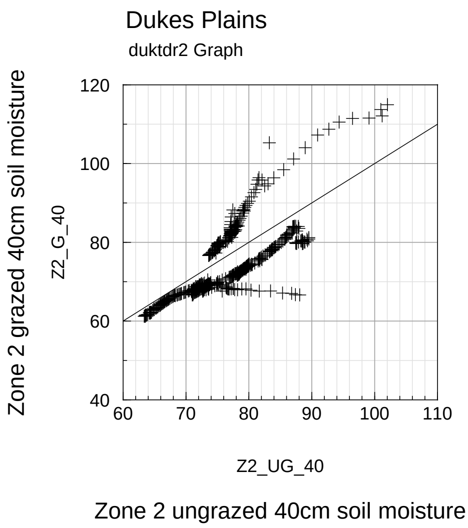


Figure 4.4.8b

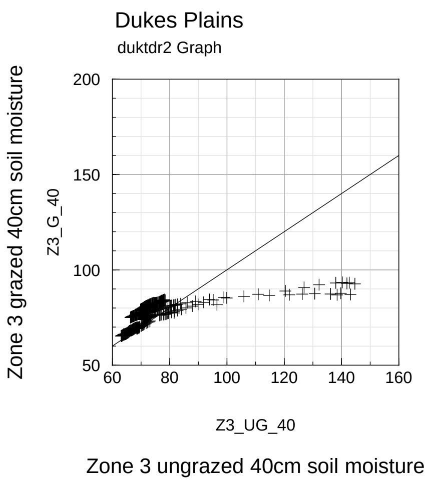


Figure 4.4.8c

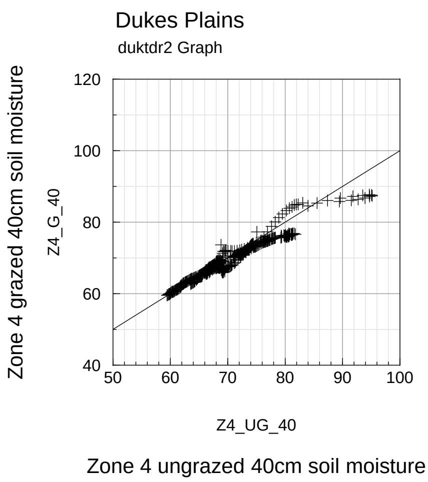


Figure 4.4.8d

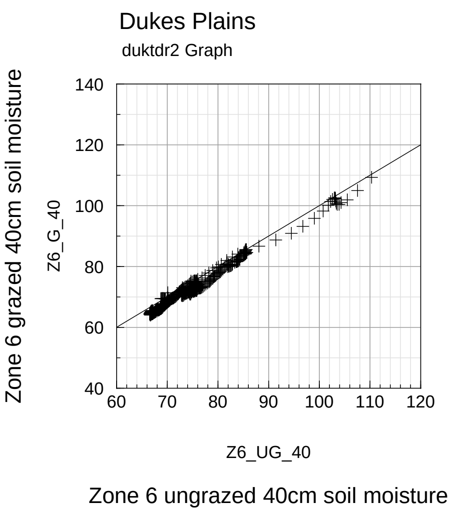


Figure 4.4.8e

Figure 4.4.8. For Duke's Plain comparison of exclosed (ungrazed) and grazed soil moisture for each zone at 40cm depth: Figure (a) Zone 1; (b) Zone 2; (c) Zone 3; (d) Zone 4 and (e) Zone 6. The one to one line is indicated.

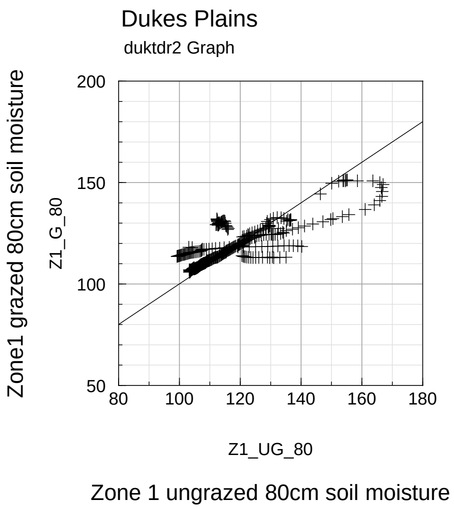


Figure 4.4.9a

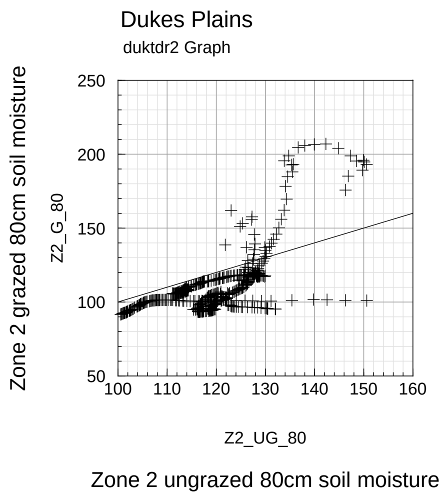


Figure 4.4.9b

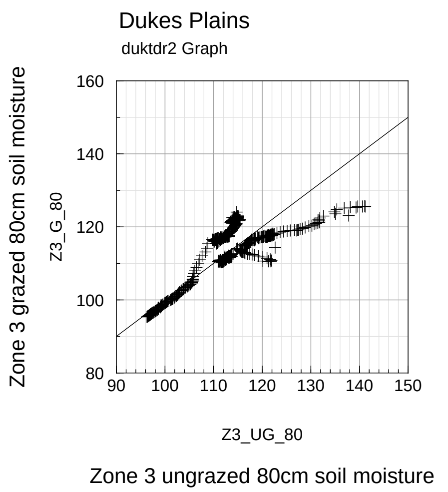


Figure 4.4.9c

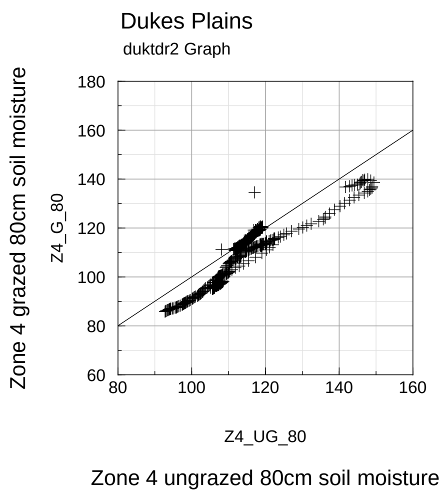


Figure 4.4.9d

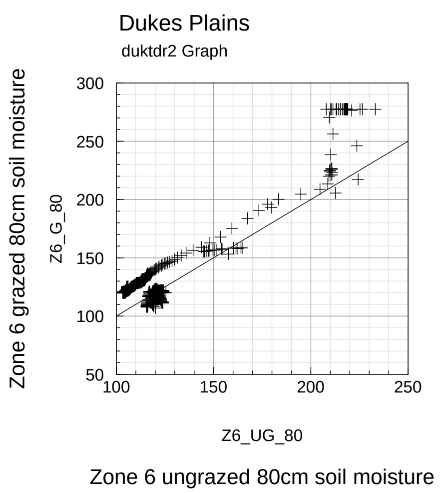


Figure 4.4.9e

Figure 4.4.9. For Duke's Plain comparison of exclosed (ungrazed) and grazed soil moisture for each zone at 80cm depth: Figure (a) Zone 1; (b) Zone 2; (c) Zone 3; (d) Zone 4 and (e) Zone 6.

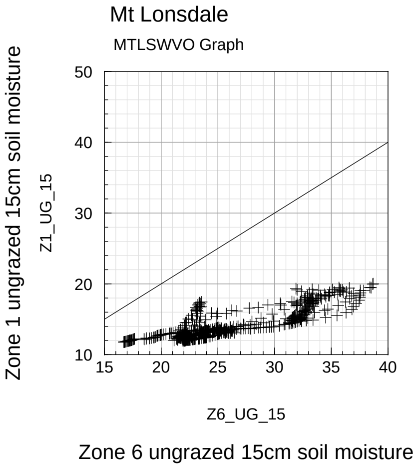


Figure 4.4.10a. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

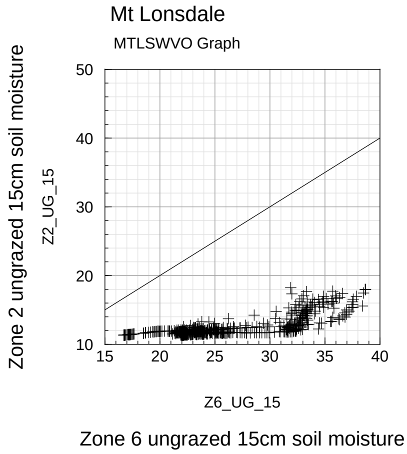


Figure 4.4.10b. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

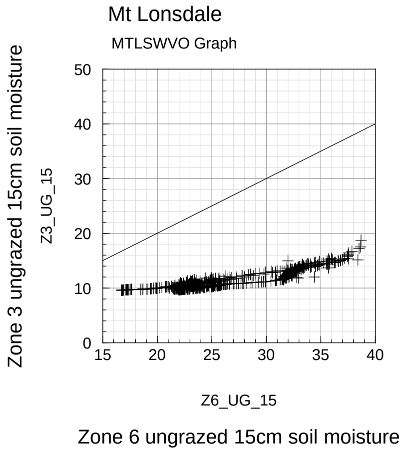


Figure 4.4.10c. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

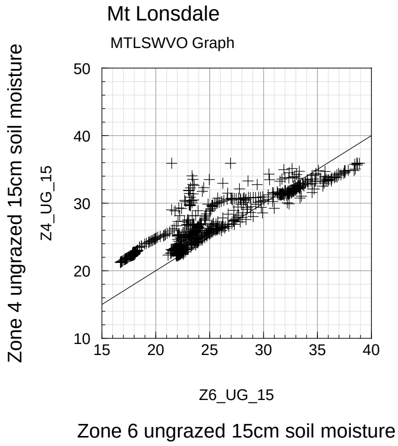


Figure 4.4.10d. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

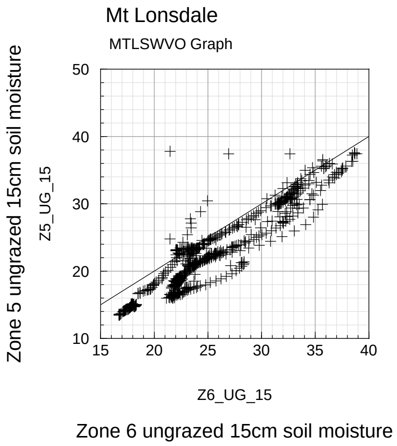


Figure 4.4.10e. The relationship between 15cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 5 (3-4 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

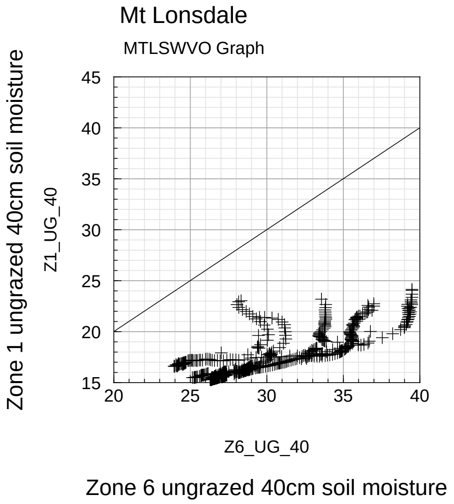


Figure 4.4.11a. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

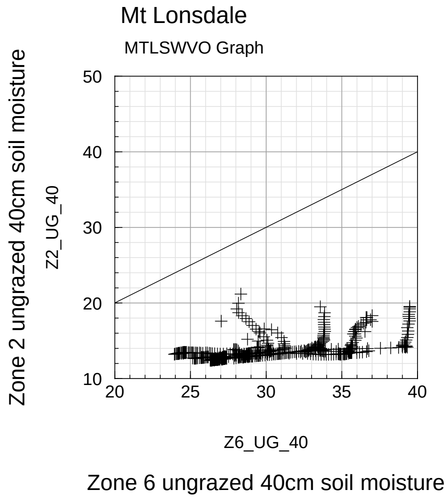


Figure 4.4.11b. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

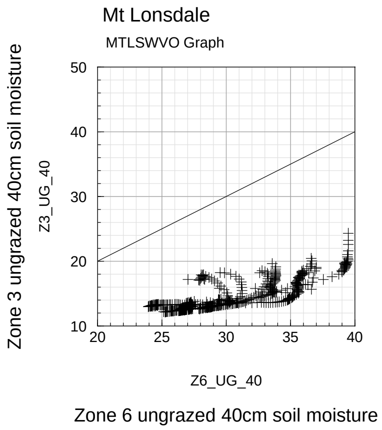


Figure 4.4.11c. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

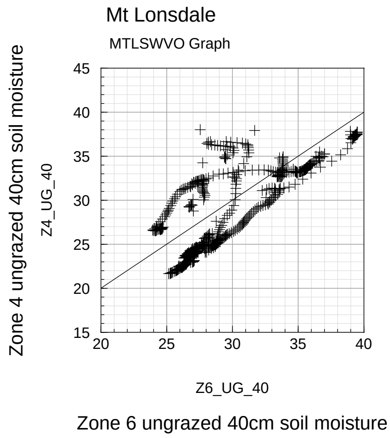


Figure 4.4.11d. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

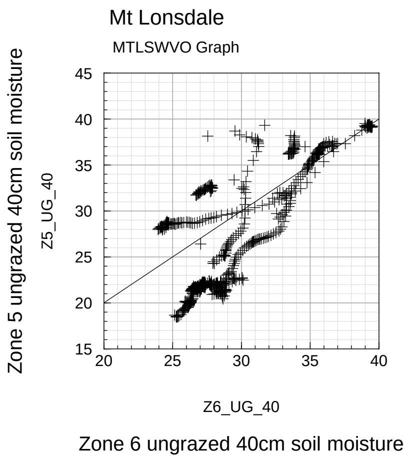


Figure 4.4.11e. The relationship between 40cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 5 (3-4 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

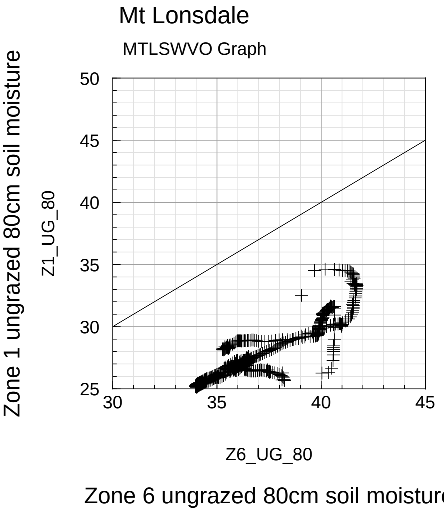


Figure 4.4.12a. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

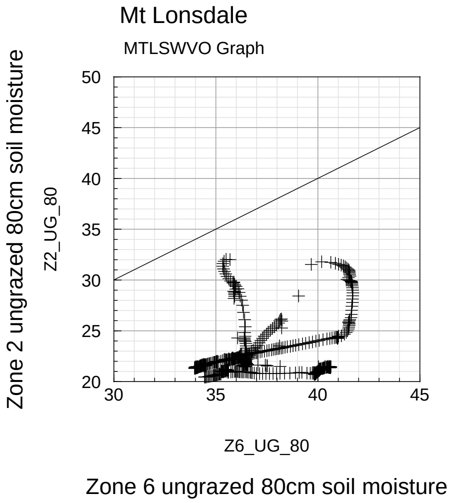


Figure 4.4.12b. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

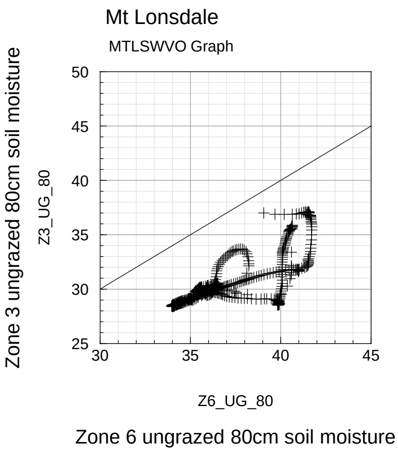


Figure 4.4.12c. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

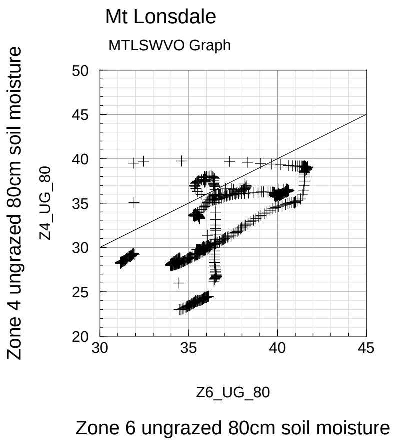


Figure 4.4.12d. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated

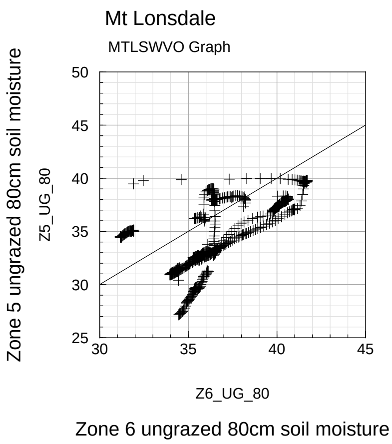


Figure 4.4.12e. The relationship between 80cm soil moisture measured in ungrazed Zone 6 compared to ungrazed Zone 5 (3-4 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

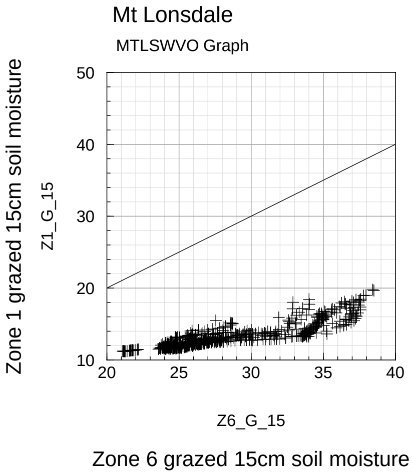


Figure 4.4.13a. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

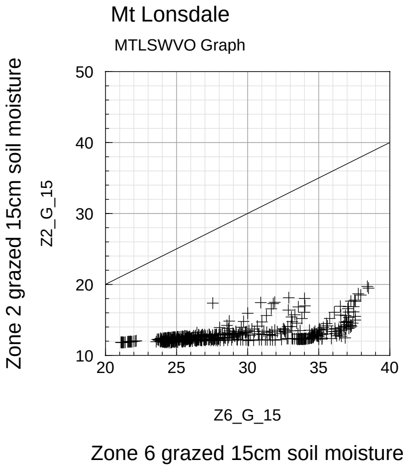


Figure 4.4.13b. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

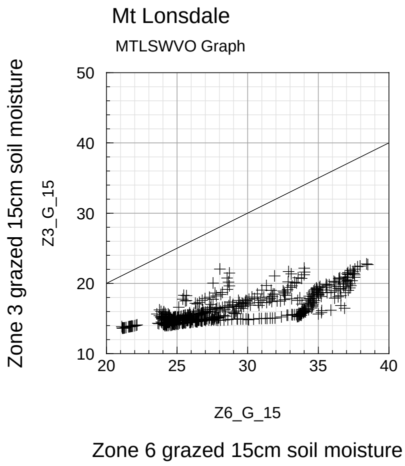


Figure 4.4.13c. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

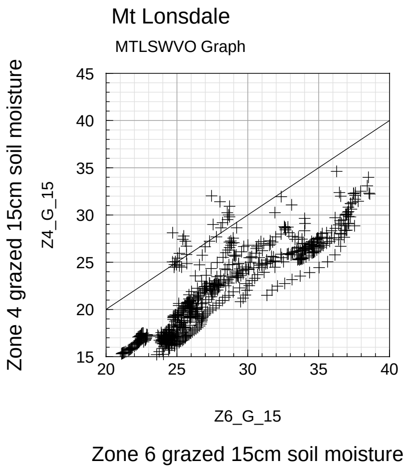


Figure 4.4.13d. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

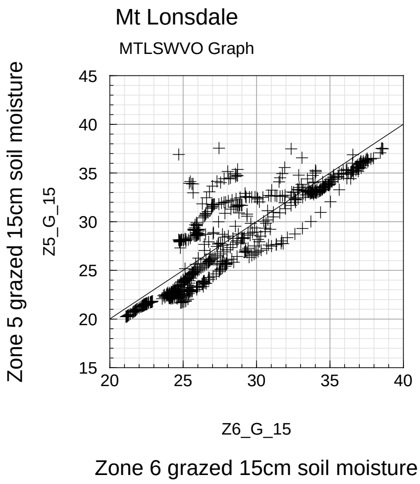


Figure 4.4.13e. The relationship between 15cm soil moisture measured in grazed Zone 6 compared to grazed Zone 5 (3-4 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

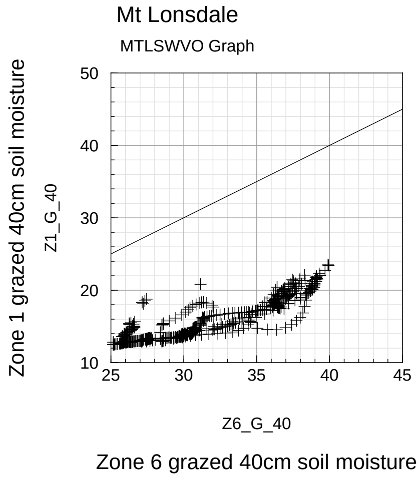


Figure 4.4.14a. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

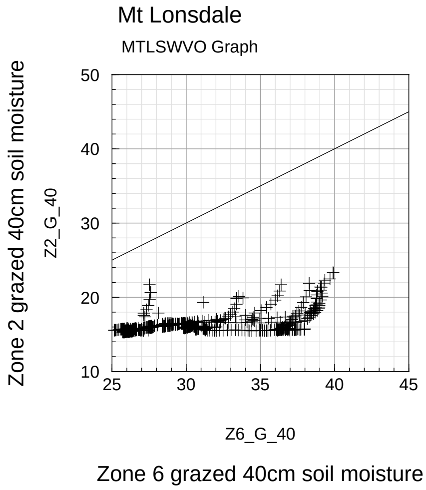


Figure 4.4.14b. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

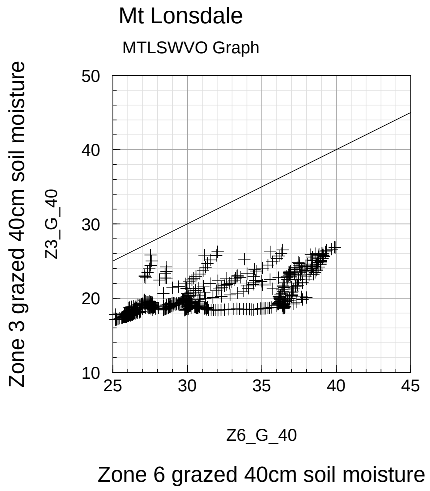


Figure 4.4.14c. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

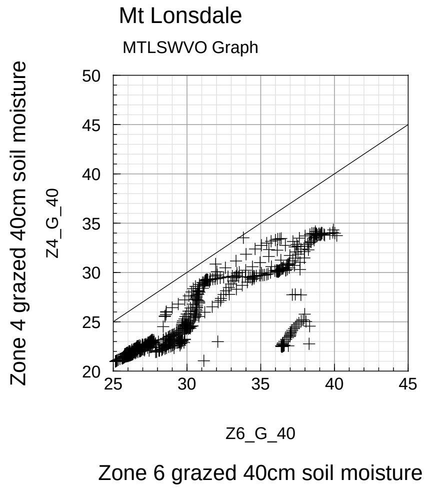


Figure 4.4.14d. The relationship between 40cm soil moisture measured in grazed Zone 6 compared to grazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

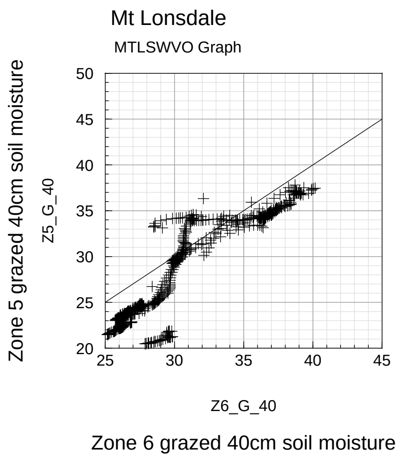


Figure 4.4.14e. The relationship between 40cm soil moisture measur in grazed Zone 6 compared to grazed Zone 5 (3-4 times the tree heig away from the tree strip canopy). The one-to-one line is indicated.

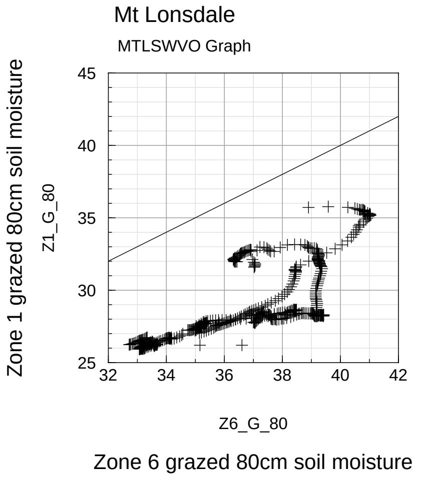


Figure 4.4.15a. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 1 (immediately outside the canopy of the tree strip and on the opposite of the strip to Zone 6). The one-to-one line is indicated.

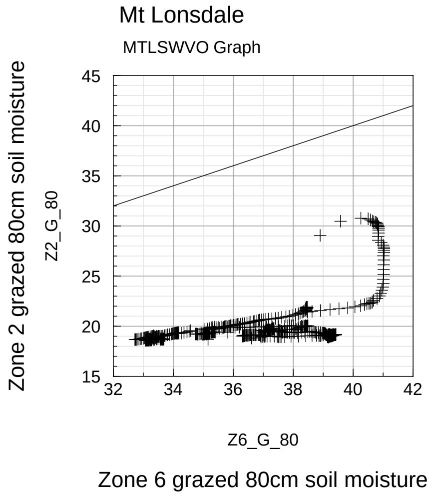


Figure 4.4.15b. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 2 (inside the tree strip). The one-to-one line is indicated.

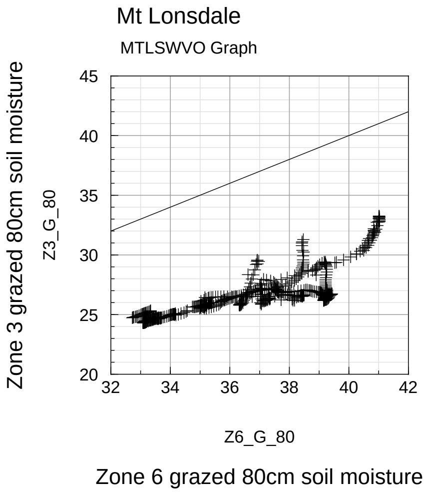


Figure 4.4.15c. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 3 (immediately outside the canopy of the tree strip and on the same side of the strip as Zone 6). The one-to-one line is indicated.

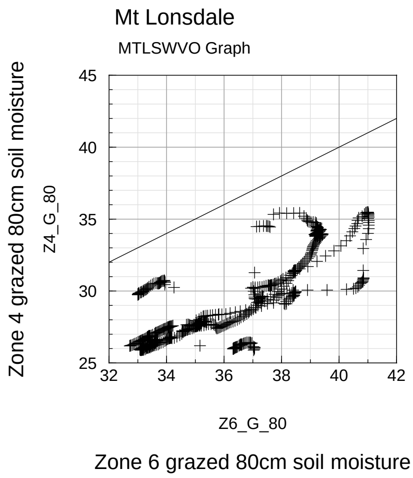


Figure 4.4.15d. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 4 (1-2 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

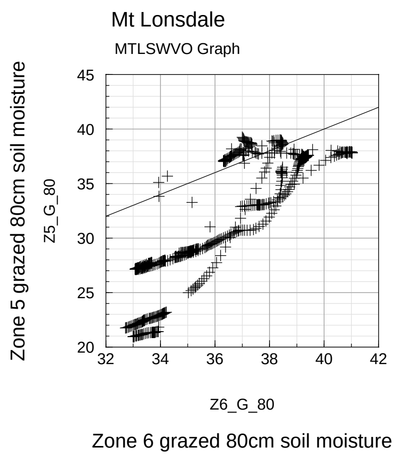


Figure 4.4.15e. The relationship between 80cm soil moisture measured in grazed Zone 6 compared to grazed Zone 5 (3-4 times the tree height away from the tree strip canopy). The one-to-one line is indicated.

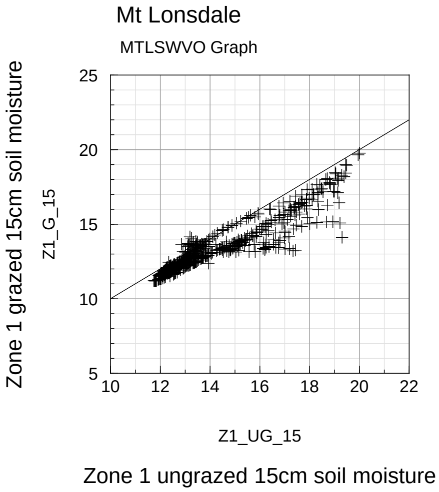


Figure 4.4.16a

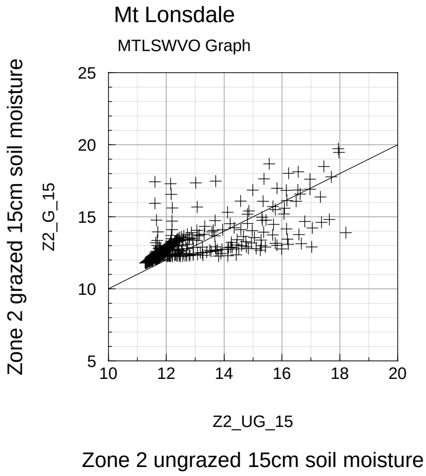
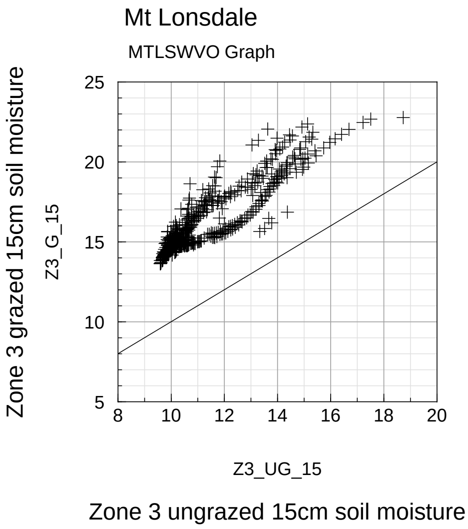


Figure 4.4.16b



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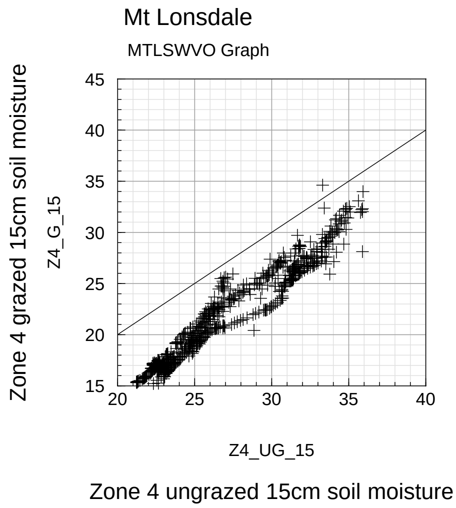

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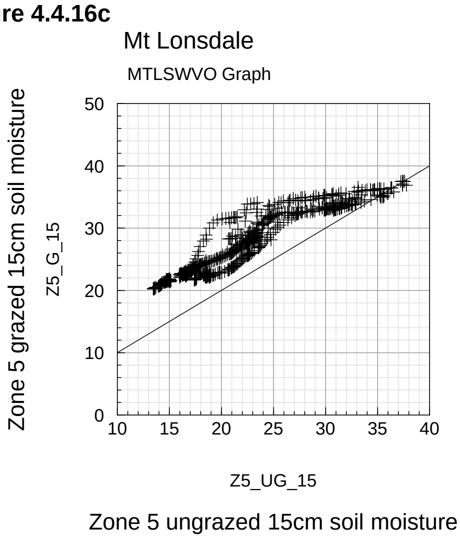

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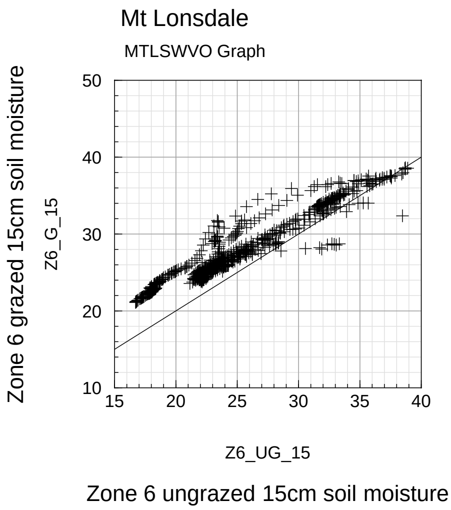


Figure 4.4.16f

Figure 4.4.16. For Mt Lonsdale comparison of soil moisture between exclosed (ungrazed) and grazed sites at 15cm depth: Figure (a) Zone 1; (b) Zone 2; (c) Zone 3; (d) Zone 4; (e) Zone 5 and (f) Zone 6.

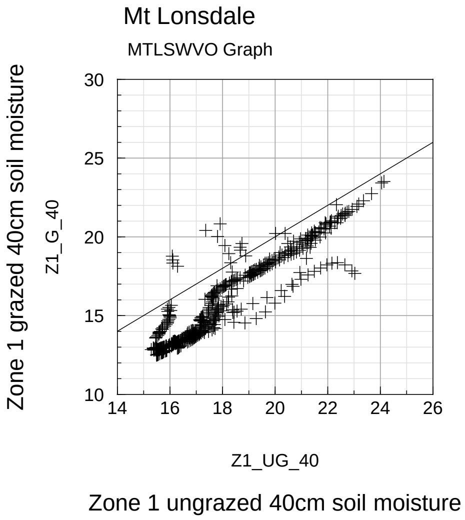


Figure 4.4.17a

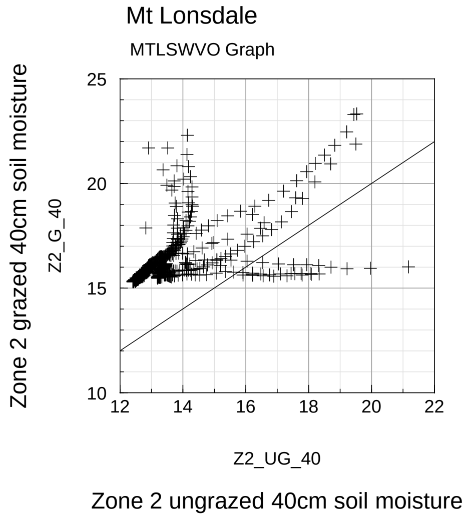
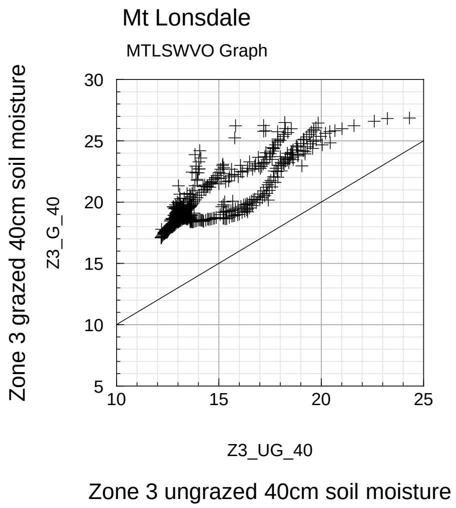


Figure 4.4.17b



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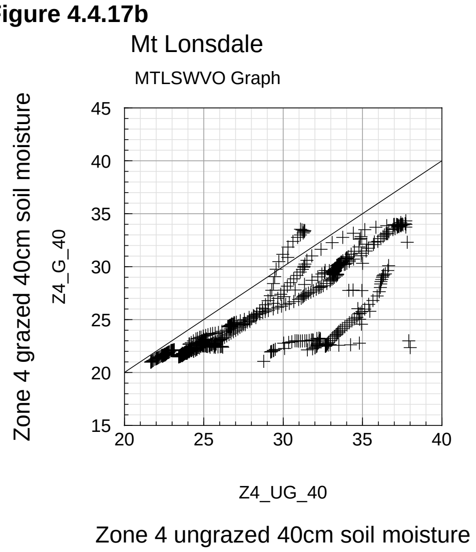

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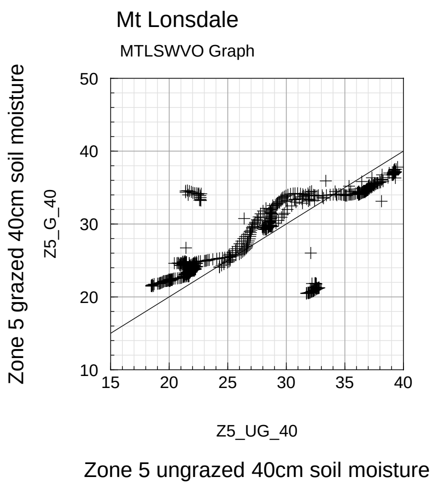

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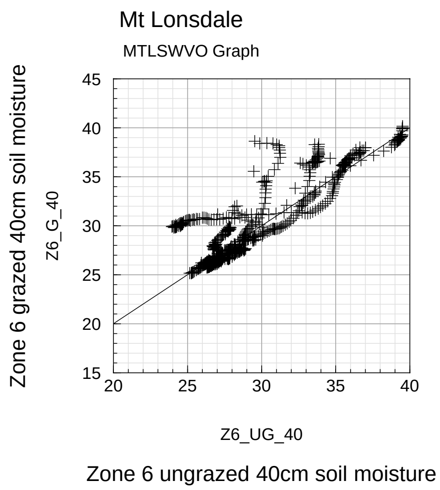


Figure 4.4.17f

Figure 4.4.17. For Mt Lonsdale comparison of soil moisture between exclosed (ungrazed) and grazed sites at 40cm depth: Figure (a) Zone 1; (b) Zone 2; (c) Zone 3; (d) Zone 4; (e) Zone 5 and (f) Zone 6.

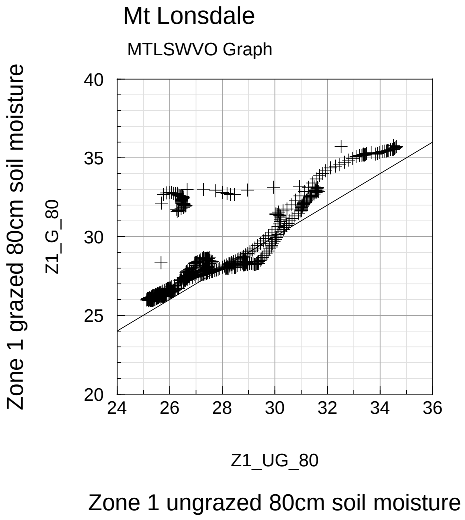


Figure 4.4.18a

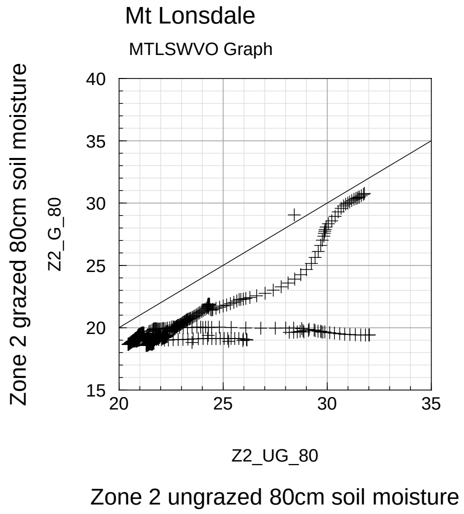


Figure 4.4.18b

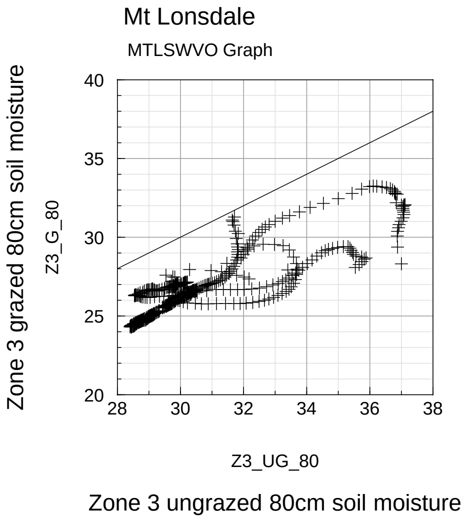


Figure 4.4.18c

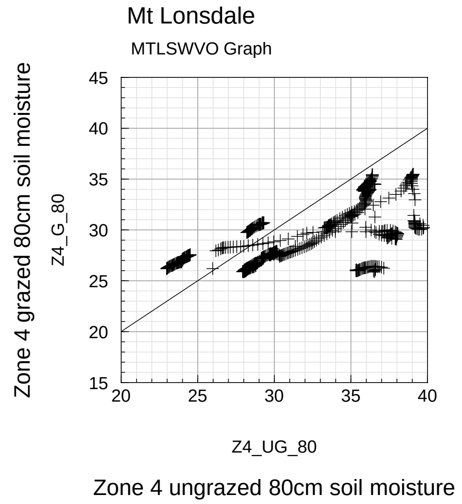


Figure 4.4.18d

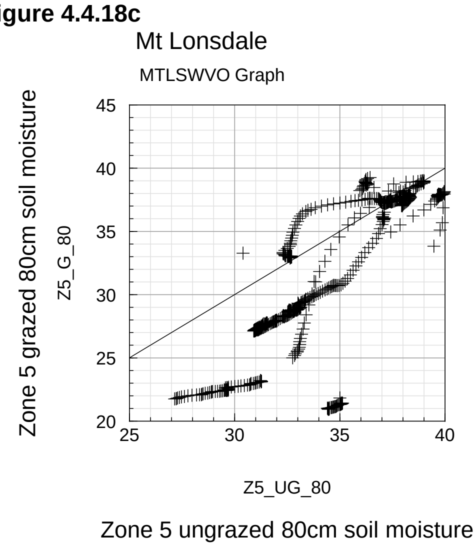


Figure 4.4.18e

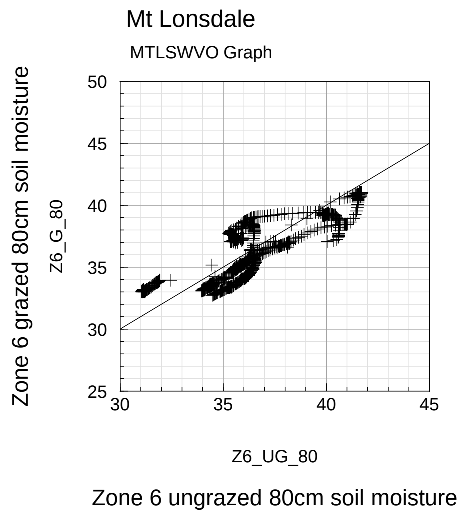


Figure 4.4.18f

Figure 4.4.18. For Mt Lonsdale comparison of soil moisture between exclosed (ungrazed) and grazed sites at 80cm depth: Figure (a) Zone 1; (b) Zone 2; (c) Zone 3; (d) Zone 4; (e) Zone 5 and (f) Zone 6.

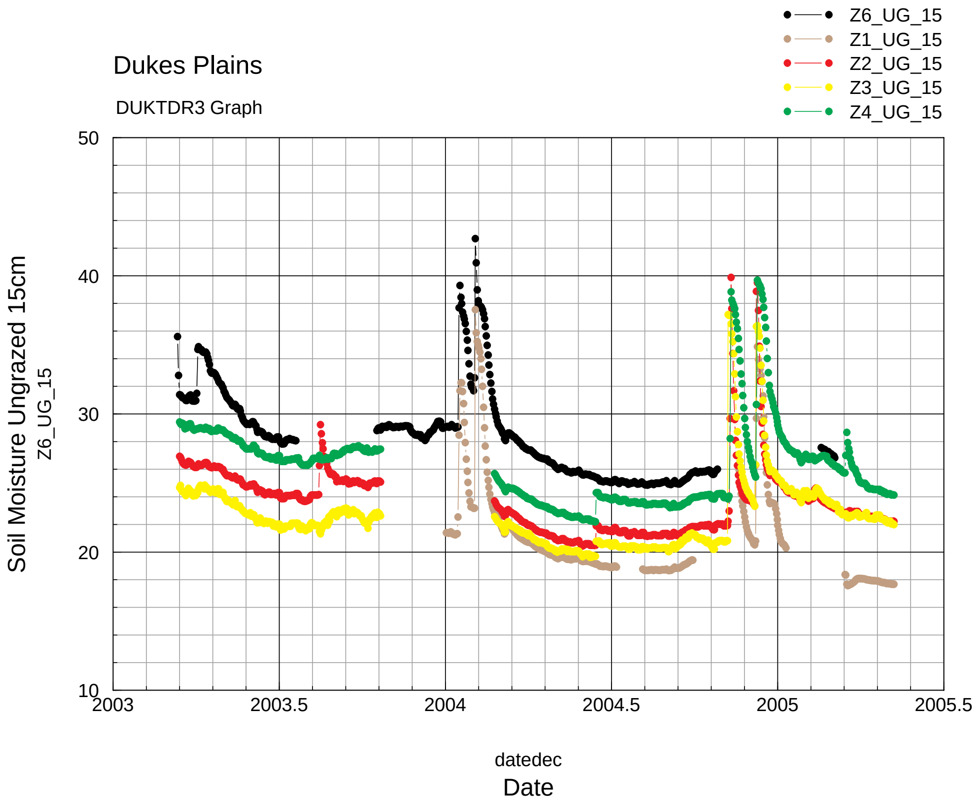


Figure 4.4.19. Time series of soil moisture ungrazed (15cm) at Duke's Plain.

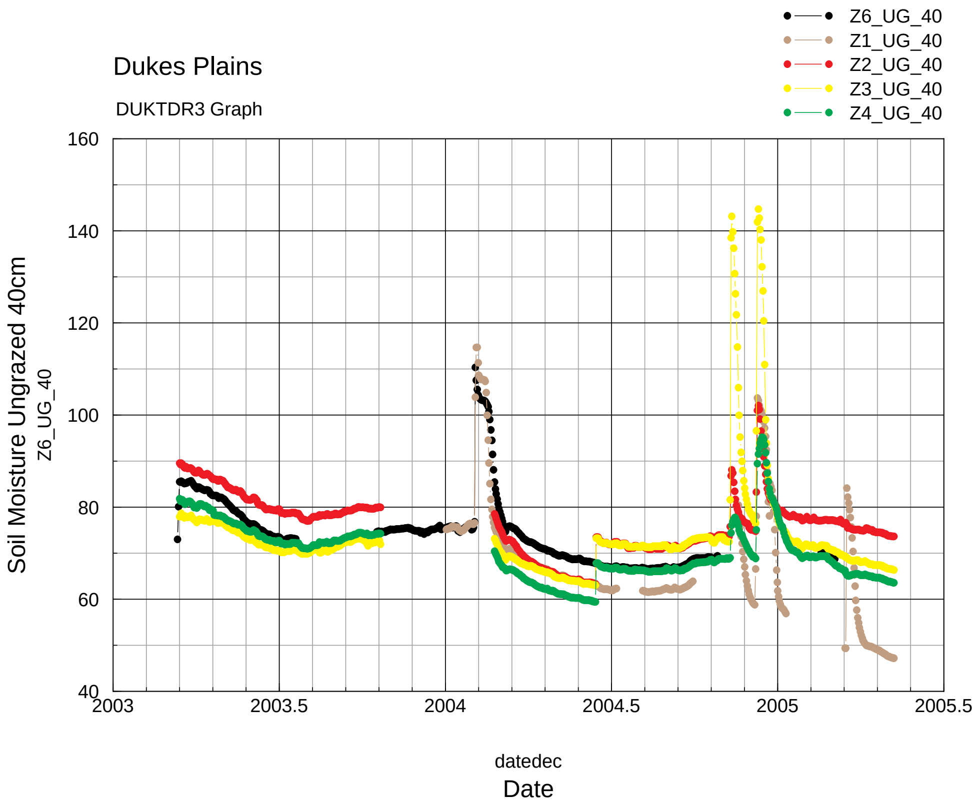


Figure 4.4.20. Time series of soil moisture ungrazed (40cm) at Duke's Plain.

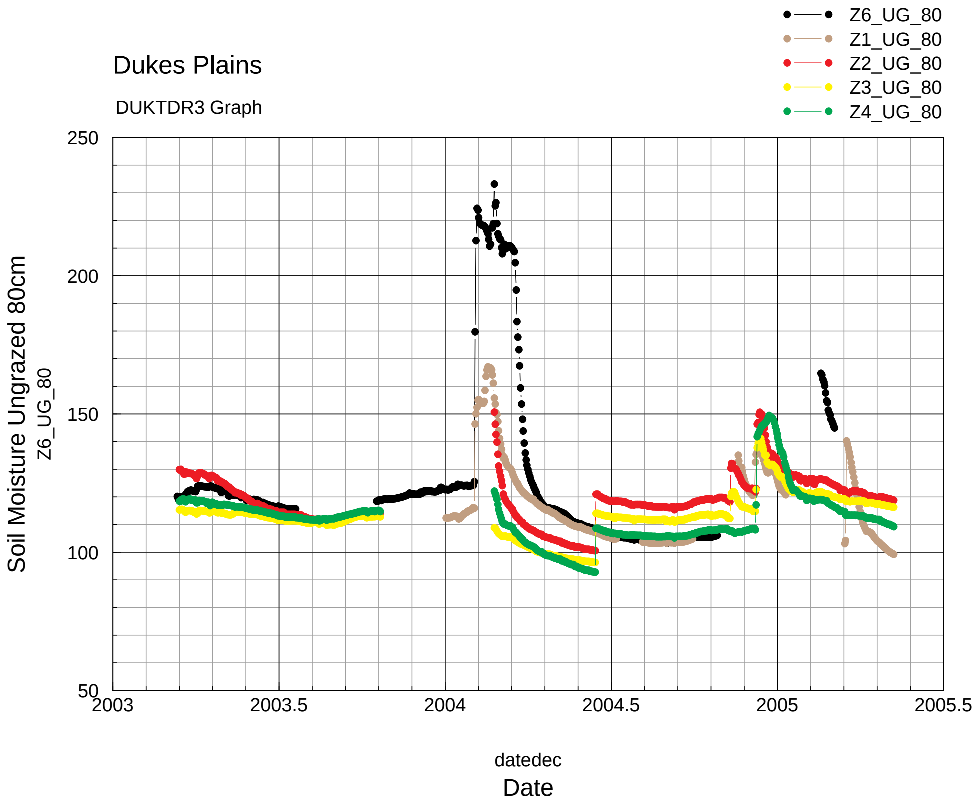


Figure 4.4.21. Time series of soil moisture ungrazed (80cm) at Duke's Plain.

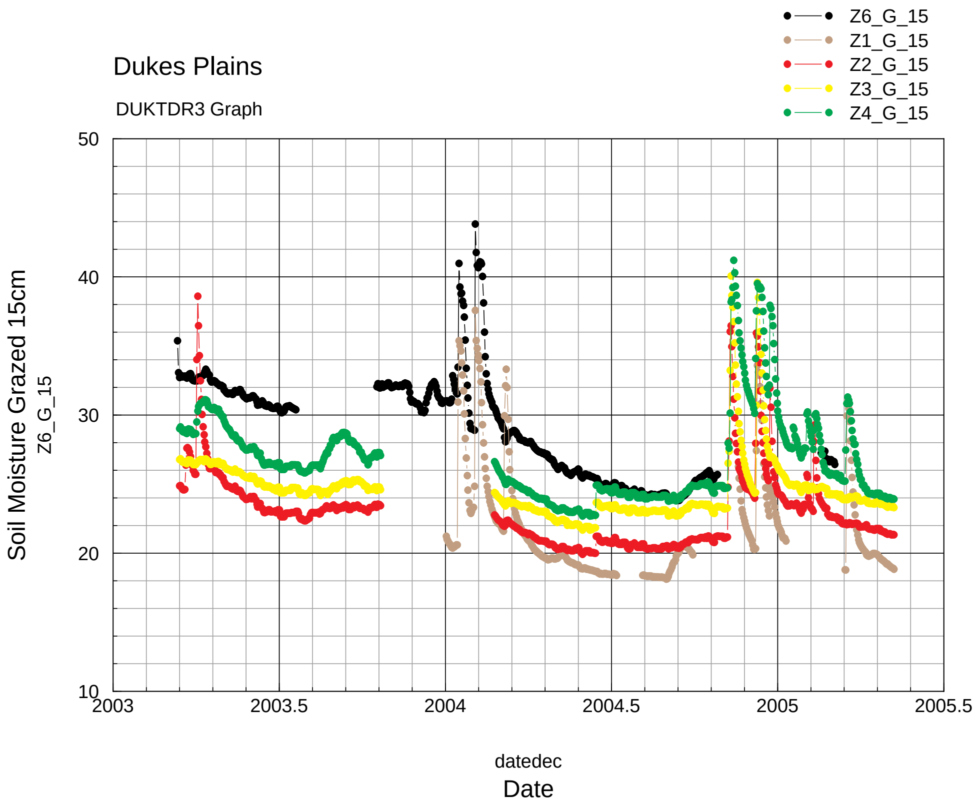


Figure 4.4.22. Time series of soil moisture grazed (15cm) at Duke's Plain.

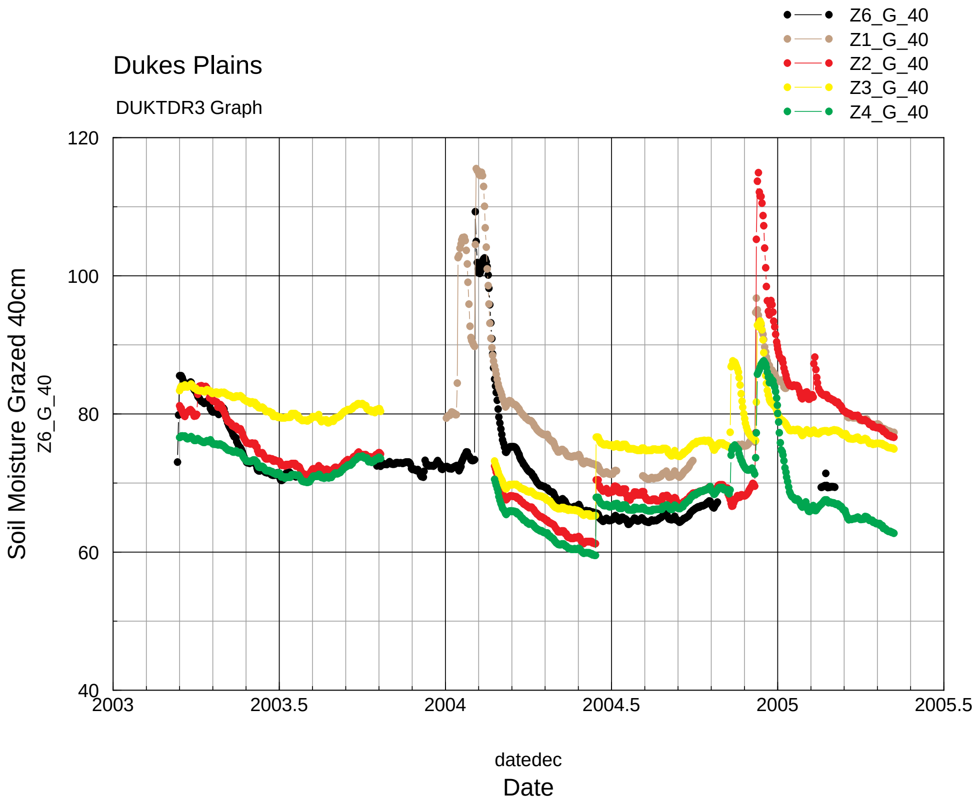


Figure 4.4.23. Time series of soil moisture grazed (40cm) at Duke's Plain.

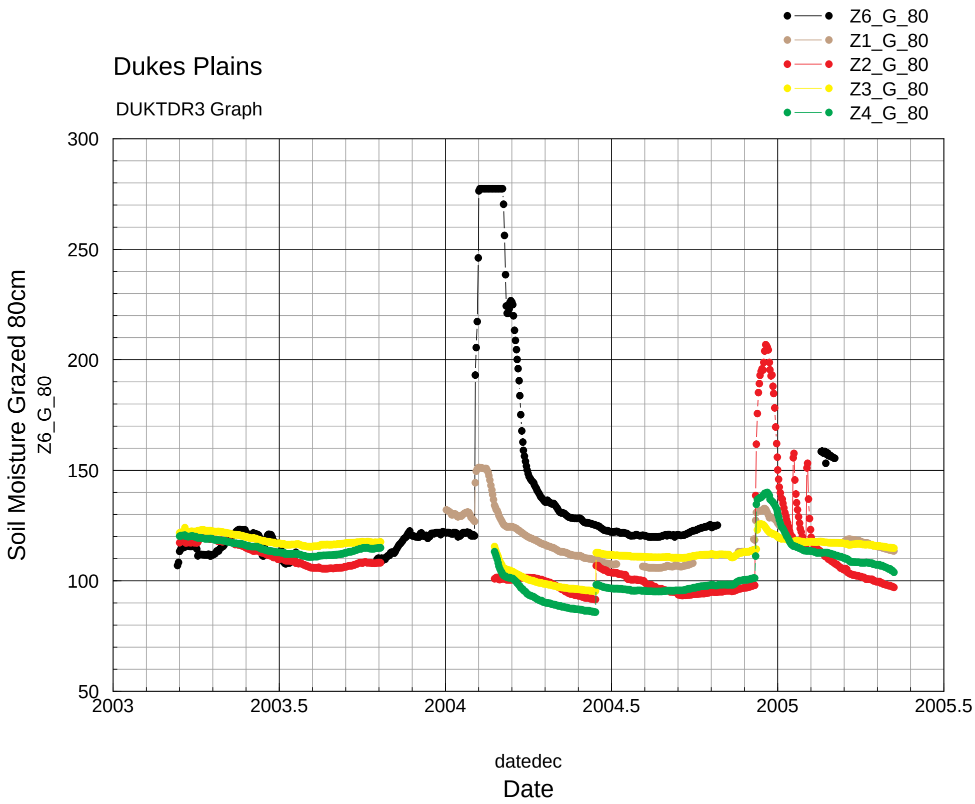


Figure 4.4.24. Time series of soil moisture grazed (80cm) at Duke's Plain.

4.4.5 Detailed analysis of soil moisture data

The soil moisture dataset collected at Mt Lonsdale provides a near-continuous measurement set from November 2003 to October 2005 and, hence, offers the opportunity to assess the impact of tree strips and grazing on soil water in detail across two growing seasons. However, it should be noted that the measurements were at single points and without replication. The measurement time series also starts immediately after installation and hence there was no period for repair of the soil disturbance necessary in installing the sensors. In Appendix 10.13, a detailed analysis concentrates on: 1) method of installation; 2) potential errors in measurement; and 3) analysis of calculated infiltration and evapo-transpiration.

As discussed in Appendix 10.9, a factor present in the replicate (Rep1) where soil moisture was measured, is variation in micro-topography associated with linear Gilgai features of the soil. As yet the effect of this factor on run-on and runoff is yet to be determined.

Plates 4.4.1 and 4.4.2 provide examples of the method of installation at Mt Lonsdale and Plate 4.4.3 shows examples of microtopography and presence of timber debris.

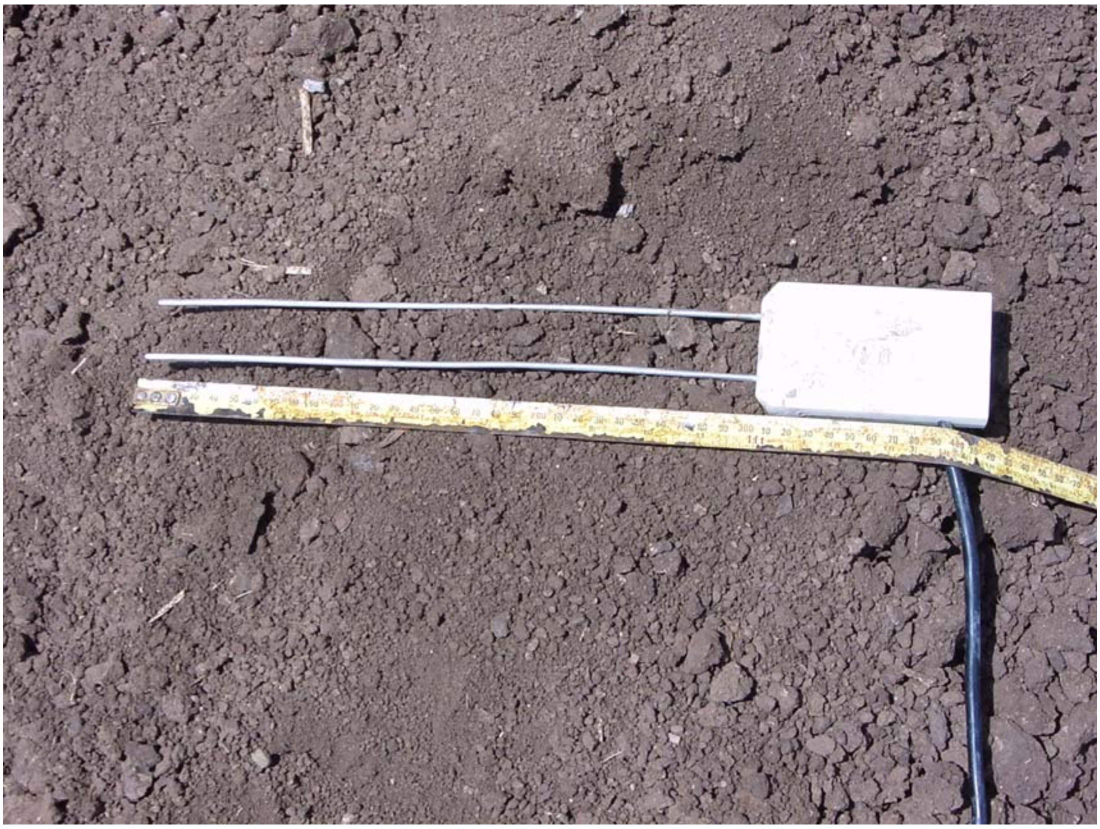


Plate 4.4.1. Campbell soil moisture sensor.

Plate 4.4.2. Installed soil moisture sensors at depths 15cm, 40cm and 80cm.

Plate 4.4.3. Examples of microrelief at Mt Lonsdale showing the impact of water redistribution on pasture growth.

4.4.5.1 Conclusion of analysis of soil moisture data

It is not possible to draw firm conclusions from the analysis since the soil water measurements are from a single site at each location and cover a limited number of events. Additionally there is a degree of uncertainty in the results due to the fact that limited soil moisture sensor calibration was undertaken.

Nevertheless, the preliminary analysis of soil moisture data at Duke's Plain and Mt Lonsdale indicated a consistent sets of data suitable for further analysis for Mt Lonsdale. Differences along the transect in infiltration and evapo-transpiration rates were indicated. The next stages in the analysis are to evaluate:

1) the differences in soil texture (particularly at Mt Lonsdale, Figure 4.3.1) along the transect to allow comparison of soil moisture in terms of matric water potential;
2) the potential role of surface runoff including the effects of micro-topography and timber debris; and
3) consistency of estimated rainfall and soil moisture data using soil water balance modelling.

4.5 The relationship between pasture standing dry matter (SDM) and transect distance expressed as a multiple of tree height

4.5.1 Introduction

General models of beneficial and competitive effects of trees on pasture growth have been suggested, (e.g. Walker *et al.* 1989, Scanlan 1992) in which the different effects of trees are a function of distance from individual trees. The studies (Walker *et al.* 1989, Scanlan 1992) indicated that relatively simple algebraic models could be constructed to account for the beneficial and competitive spatial effects of trees. In the following section we have further examined simple empirical descriptions of the beneficial and competitive effects of tree strips and the implications of these relationships in calculating the overall effect of tree strips on paddock pasture production.

The following analysis is based on the assumption that the effects on pasture standing dry matter are a result of the beneficial and competitive effects of tree strips. However, as indicated earlier, other effects related to systematic soil features and/or mechanical disturbance during the various phases of tree clearing and regrowth could also contribute to the observed pattern of pasture growth along the transect perpendicular to the tree strip. At this stage of preliminary analysis these possible soil effects are not considered and the following empirical model is formulated on the basis of separating beneficial and competitive effects of the tree strip.

As reported in previous sections, pasture standing dry matter (SDM) was sampled on a transect perpendicular to the tree strip. Previous studies of wind break impacts (Cleugh 2002) indicated that tree effects on pasture and crops were best represented along transects in terms of multiples of tree height. This approach has been evaluated and used in the following analysis. Transect has been divided into Zones (Table 4.5.1) to aid description of the influence of trees along the transect:

- Zone 1 Immediately adjacent to tree strip on short side of transect with average distance 0.3-0.8multiples of tree height.
- Zone 2 Within tree strip. At Duke's Plain and Mt Lonsdale, strip were ≈ 2-5 multiples of tree wide.
- Zone 3 Immediately adjacent to tree strip on long side of transect with average distance 0.2-0.5 multiples of tree height.
- Zone 4 Mid transect with average distance 1-2 multiples of tree height.
- Zone 5 Open pasture with average distance 3-4 multiples of tree height.
- Zone 6 Open pasture with average distance 6-8 multiples of tree height.

Table 4.5.1. Average distance of zones from edge of tree strip in multiples of tree height. Two heights have been used for Moombah reflecting the different tree structure.

Zone	Duke's Plain	Mt Lonsdale	Moombah Height = 20m	Moombah Height = 12m	Range Across Locations
1	0.65	0.32	0.49	0.81	0.32 – 0.65
2	2.3A	2.5A	3.2A	5.4A	-
3	0.46	0.21	0.24	0.40	0.21 – 0.46
4	1.46	1.11	1.27	2.13	1.11 – 2.13
5	3.15	3.14	3.58	5.96	3 – 6
6	6.85	6.31	7.68	12.79	6 – 13

A – Tree strip width in multiples of tree height.

The following analysis examines (1) representation of pasture transect data in terms of % of Zone 6 (open pasture) farthest from tree strip and distance expressed in terms of tree height; (2) development of an empirical model of beneficial and competitive effects in the pasture transect (Zones 3 to 6); (3) pasture growth within the tree strip (Zone 2) and development of a model within the strip; and (4) the calculation of accumulated pasture growth at paddock scale using combined models of within tree strip and pasture transect.

Wherever possible, in the following analysis we have used the term 'x tree height' as the measure of distance scale. In the literature e.g. Cleugh 2002 the term is abbreviated as 'H' and we used this abbreviation as well as *mth* where it is appropriate.

This section contains over 60 graphs. To maintain the integrity of links to source data files, the file name of each CoPlot™ draw file and column captions have been included. These will be removed in final publication but have been retained here to allow rapid response to review and updated analyses.

4.5.2 Summary of pasture transect SDM measurements

Figures 4.5.1 and 4.5.2 show the transects of pasture SDM from Zones 3-6 expressed as multiples of tree height from the edge of the tree strip. The five combinations of location x year have been expressed as the mean of the 3 tree strips at each location. For each combination, SDM is calculated as the percentage of the average SDM for Zone 6. Thus, Figures 4.5.1 and 4.5.2 provide an approach of comparing the five combinations of location x year on a common basis, i.e. SDM as a percentage of Zone 6 and distance from the tree strip as a multiple of tree height. In the case of Moombah, the lower tree height (12 metres) of the dominant woody shrub species has been used. Figure 4.5.1 shows the relationships for the individual location x year combinations, Figure 4.5.2A shows all five combinations, Figure 4.5.2B shows only four combinations, namely the two years at Duke's Plain and the two years at Mt Lonsdale, and Figure 4.5.2C shows data for distances less than 4 x tree height highlighting the competitive and beneficial zones of tree strip influence.

The above figures indicated peaks in measured pasture SDM at approximately 2 x tree height for four of the five location x year combinations (Figure 4.5.1). Given the large difference in tree height between Duke's Plain (6.5m) and Mt Lonsdale (18m) the correspondence of peak SDM at similar multiples of tree height supports the use of tree height in investigating effects across locations and tree strip attributes. The exception was Moombah in 2005 where maximum SDM occurred at 0.5 - 1 x tree height depending on the tree height that best represented the tree strip (Table 4.5.1). The pasture data for Moombah requires more detailed investigation including the possible effects of strip orientation, age of clearing, presence of ash beds and other soil disturbance (blade ploughing).

Although the tree strips at Duke's Plain and Mt Lonsdale had different orientations, tree basal area and tree height (Table 3.1.1), a general model was suggested in which there is a strong competitive effect of the tree strips from the edge of strip to a distance of 0.5 x tree height. From 0.5 to 6 x tree height, pasture SDM exceeded the average pasture SDM measured in Zone 6. At Duke's Plain the decline in relative pasture SDM continued through Zone 6 at the end of the transects suggesting some declining beneficial influence of tree strips may still be present at Zone 6. In contrast, at Mt Lonsdale, pasture SDM appeared to plateau at the end of the transects.

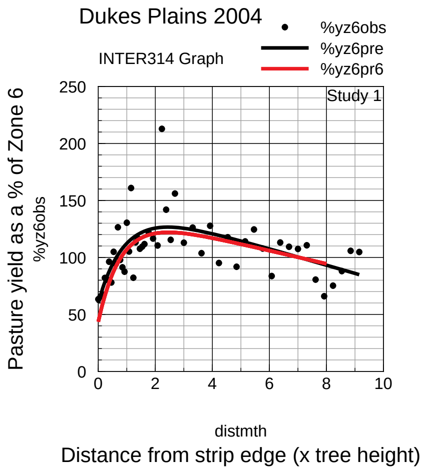


Figure 4.5.1a

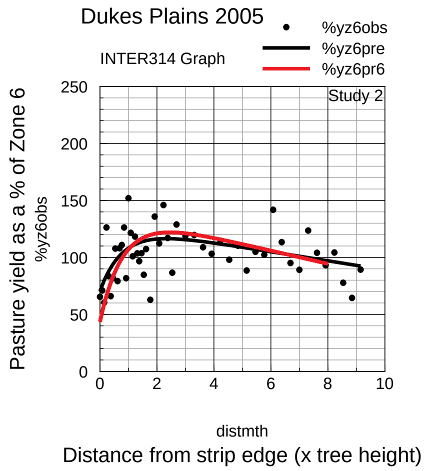


Figure 4.5.1b

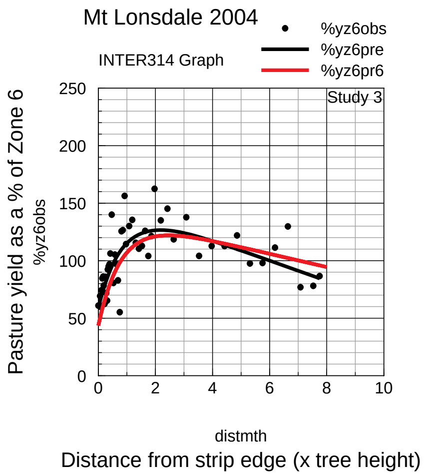


Figure 4.5.1c

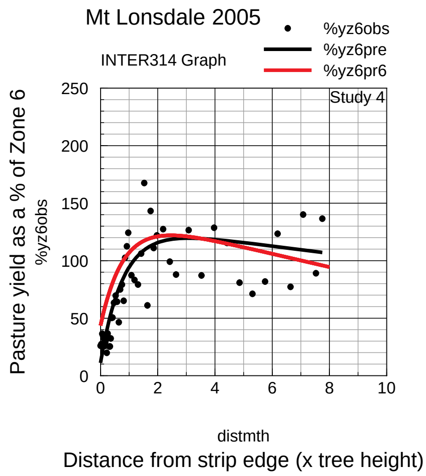


Figure 4.5.1d

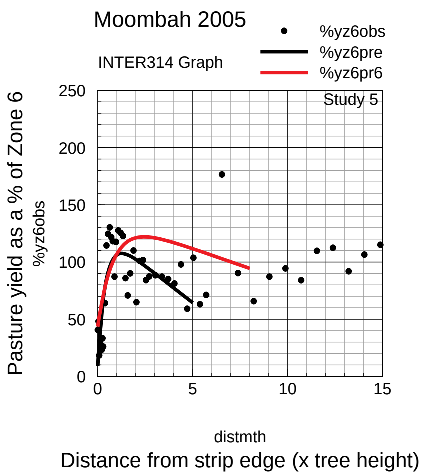


Figure 4.5.1e

Figure 4.5.1 The relationship between pasture standing dry matter (yield) expressed as a percentage of Zone 6 average yield and distance from the edge of the tree strip expressed in multiples of tree height. Data is presented for Duke's Plain and Mt Lonsdale for 2004 and 2005 (a), (b), (c) and (d), and for Moombah for 2005 (e). Two lines are shown (black) fitted relationship (Equation 4) for location x year combination, and (red) fitted relationship for 4 combinations, 2004 and 2005 at Duke's Plain and Mt Lonsdale.

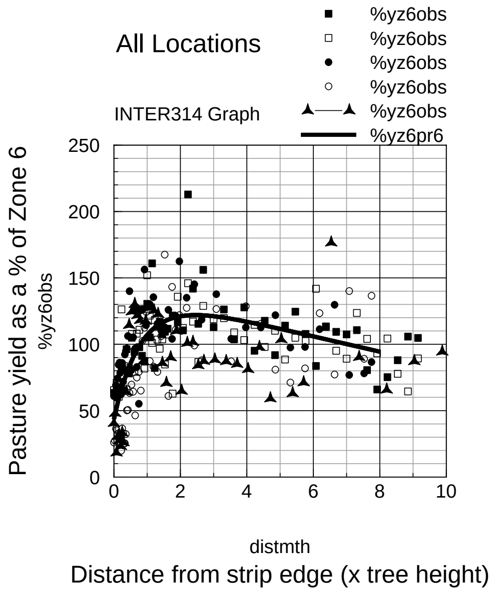


Figure 4.5.2a

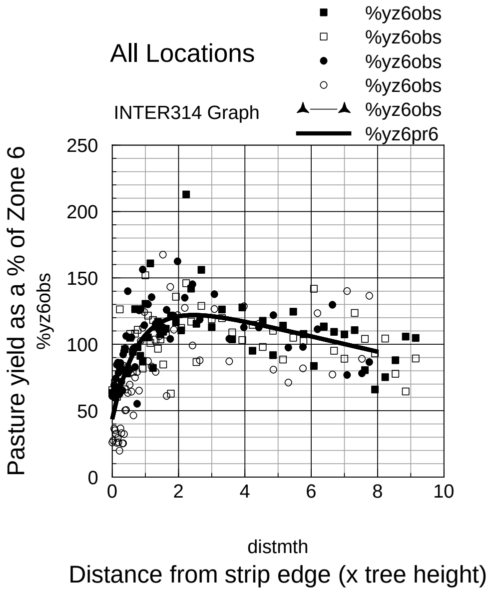


Figure 4.5.2b

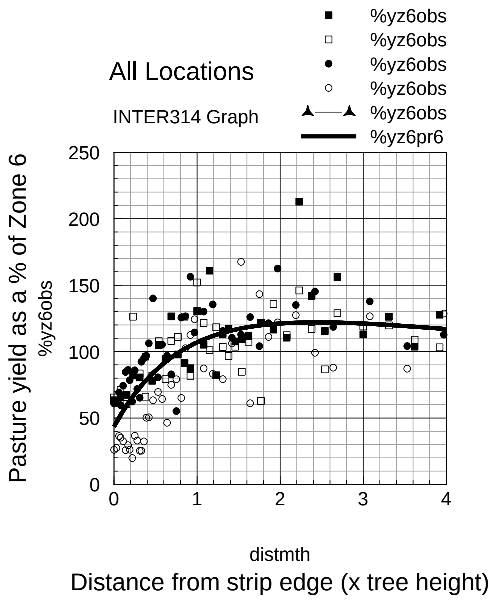


Figure 4.5.2c

Figure 4.5.2. The relationship between pasture standing dry matter (yield) expressed as a percentage of Zone 6 average yield and distance from the edge of the tree strip expressed in multiples of tree height for different combinations of location and year. Data is presented for Duke's Plain (DUK) and Mt Lonsdale (MTL) for 2004 and 2005, and for Moombah (MOO) for 2005. Duke's Plain 2004 (■), Duke's Plain 2005 (□), Mt Lonsdale 2004 (●), Mt Lonsdale 2005 (○) and Moombah 2005 (▲). The same data has been presented in three figures to show different features: Figure (a) has the relative pasture years for all five combinations of location and year; Figure (b) shows only the data for Duke's Plain and Mt Lonsdale for 2004 and 2005; Figure (c) shows all five combinations concentrating on the distance from strip edge up to four times tree height. The solid line shows the model (Equation 4) fitted for the combined data at Duke's Plain and Mt Lonsdale for 2004 and 2005.

4.5.3 Empirical model formulation

The approach adopted was to consider a transect perpendicular from the edge of the tree strip to the open, i.e. Zones 3 to 6 in pasture transects described above. As indicated in the review of tree strip effects (Section 1), and measurements in Sections 4.1 and 4.3, tree strips are likely to increase potential pasture growth through (a) reduced evaporative demand (lower wind, solar radiation and VPD); (b) greater nutrient availability from litter fall and possible nitrogen fixation from leguminous trees; and (c) improved soil attributes such as infiltration and soil carbon. Analysis of wind break effects on crops suggest potential beneficial impacts of trees occur at ≈5 x height (Carberry *et al.* 2002, p887). Trees also compete with pasture for available soil moisture and nutrients, with tree roots being capable of extending the competitive effect some multiples of tree height (H) from the tree strip (e.g. 1-3H, Cleugh *et al*. 2002, p649). Thus the influence of a tree strip is hypothesised (after Scanlan 1992) to be the multiplication of two components:

1) potential pasture growth (i.e. considering only the beneficial effects of the tree strip); and
2) proportion of potential achieved after tree competition has been considered.

In preliminary studies (Appendix 10.7), different algebraic relationships describing the beneficial and competitive effects on pasture growth were evaluated with smoothed transect data (running means of adjacent four quadrats). The different algebraic forms have different implications when extrapolated beyond the transect distances measured in this study. Whilst SDM at end of the transect might be expected to plateau (asymptote) to open pasture, in reality the effects of adjacent tree strips, woodland areas, local topography, and soil disturbance are likely to influence SDM measurement at the end of the transect. Hence in the following analysis we have adopted the approach of using the simplest relationship (linear decline in beneficial effect away from trees) and not extrapolating beyond the end of the transect sampling (8 x tree height).

In choosing a plausible algebraic relationship to represent the beneficial effects, we considered the results from field experiments (e.g. Wilson 1996), where tropical grass growth had been measured under shade cloth (i.e. without the competition for water and nutrients that occurs under or adjacent to a tree canopy). Wilson (1996) found that shade (50% of sunlight) stimulated shoot growth by 9-37% depending on species. The highest increase was for green panic, a pasture species occurring at the tree strip edge at Duke's Plain. Similarly, Healey *et al*. (1998) measured an 18% increase in tropical grass growth in one shading treatment. Other studies have found greater effects up to 200% attributed to increased soil fertility. Thus a wide range, e.g.10-100%, of potential beneficial effects close to the edge of the tree strip would be consistent with field and glasshouse studies.

The following 'constrained linear' model was formulated to separate beneficial and competitive effects. The components are presented in Figure 4.5.3. In the simplest form, potential growth of pastures (y_{pot}) is represented as a linear function of distance (x) from the strip edge (equation 1). If there were no beneficial effects of trees then b_1 would be zero and potential pasture growth would be a constant across the transect.

$y_{pot} = a_1 + b_1 x$ (Equation 1, Figure 4.5.3a)

The proportion of resources (water and nutrients) used by trees is hypothesised to decline exponentially from the edge of the tree strip

$p_{trees} = b_2 .\ e^{-kx}$ (Equation 2, Figure 4.5.3b)

where b_2 is the proportion used by tree at the edge of the strip.

Thus, the proportion of resources available for pasture growth along the transect is

$1 - b_2 e^{-kx}$ (Equation 3, Figure 4.5.3c)

where $(1 – b_2)$ is the proportion of potential growth at the edge of the tree strip (i.e. when $x = 0$).

Thus the overall multiplicative model for actual pasture growth (y_{act}) is given by

$y_{act} = (a_1 + b_1 x).(1 - b_2 e^{-kx})$ (Equation 4, Figure 4.5.3d)

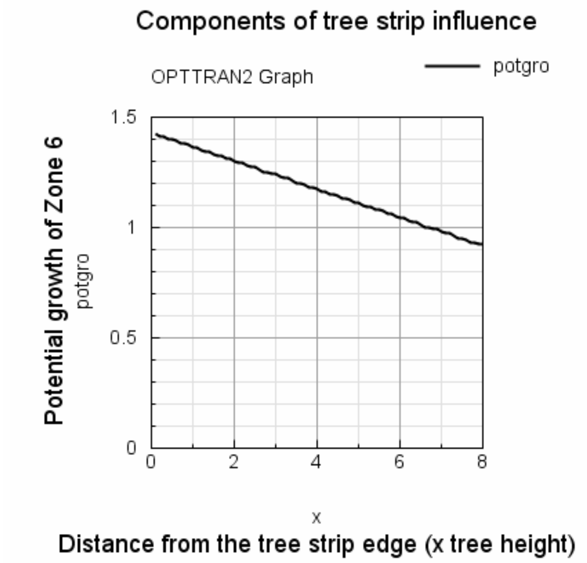


Figure 4.5.3a

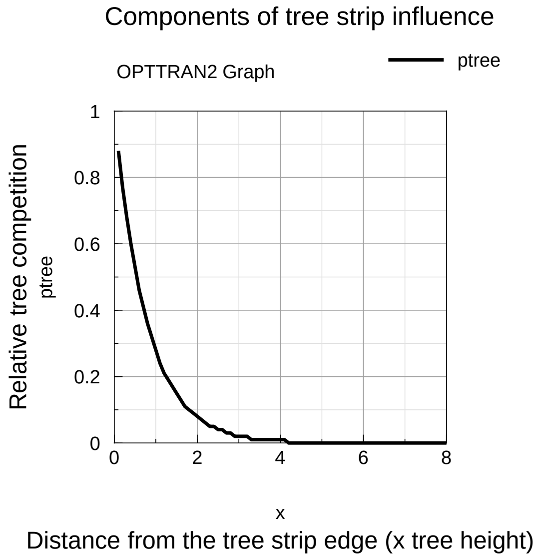


Figure 4.5.3b

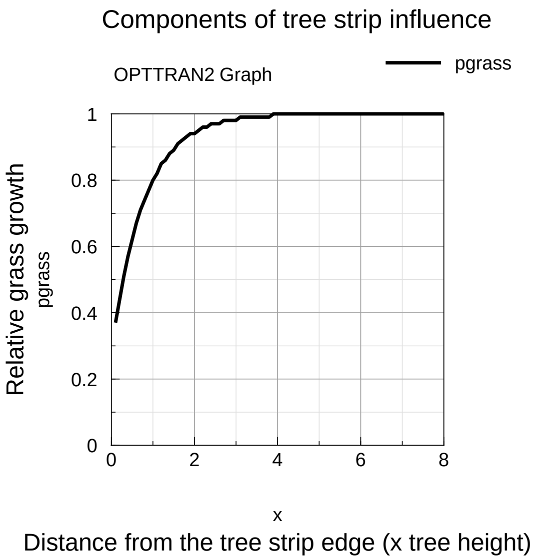


Figure 4.5.3c

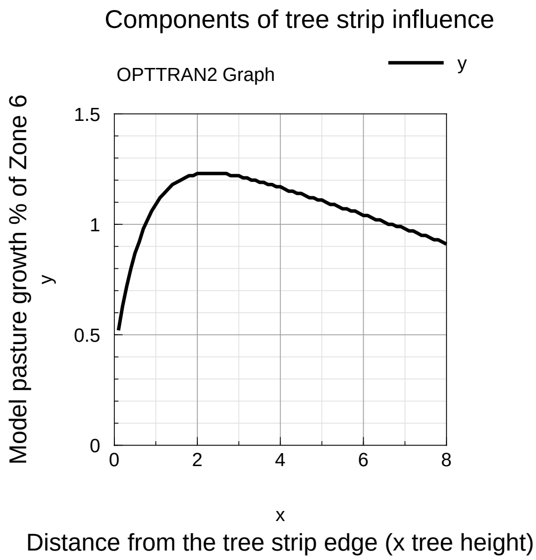


Figure 4.5.3d

Figure 4.5.3. The components of tree strip influence as given in the model development described in the text. Coefficients are from the values fitted for SDM averaged across three tree strips for the two locations and two years (Figure 4.5.2, Table 4.5.2). Figure (a) shows the model component describing potential growth of pastures (y_{pot} equation 1). Figure (b) is the relative tree competition component assuming an exponential decline from the edge of the tree strip (equation 2). Figure (c) shows the proportion of the resources available for pasture growth (equation 3) and is used to modify potential growth. Figure (d) shows the net result of combining potential pasture growth with the competitive effects of trees (equation 4). Pasure growth was averaged across Zone 6 approximately 4.5 to 8 x tree height (Table 3.1.5).

To test the above model, individual transect data of pasture standing dry matter (SDM) were 'normalised' using the procedure as described above:

1) transect distance from the edge of tree strip was expressed as a multiple of tree height; and
2) pasture standing dry matter at each point on the transect was expressed as a % of Zone 6 SDM.

However, previous windbreak studies (Cleugh *et al*. 2002, p 661) in their review of the Australian National Windbreaks Program, suggested that the zone of potentially enhanced crop or pasture growth, known as the Quiet zone, is 2-8 x tree height from the tree strip. They pointed out that the effects of windbreaks occur out to 10-20 x tree height. Thus, in our analysis we could not assume that Zone 6 (about 3-8 x tree height) was not affected by the tree strip. As a result, we fitted the above 'constrained linear' model to avoid assuming that there was no change in relative pasture SDM across Zone 6.

The pasture transect data from Moombah indicated high variability in adjacent quadrats, due to the effects of ash beds and other discontinuity features resulting from different timing of pasture establishment (Section 3,1, Appendix 10.9) (Figure 4.5.1.E). The tree strip orientation (east-west) was also substantially different to the other locations. Thus Equation 4 was fitted for the following combinations of data from Duke's Plain and Mt Lonsdale (Table 4.5.2):

1) individual tree strip transects for each year (each data point 0.5 x 0.5m quadrats);
2) average across tree strips at each location for each year (i.e. SDM averaged across three tree strips, each data point representing three 0.5 x 0.5m quadrats or $0.75m^2$); and
3) all data for combinations of locations, years and strips, each data point representing three 0.5 x 0.5m quadrats (or $0.75m^2$).

Table 4.5.2 shows the fitted coefficients (parameters) of Equation 4 for each of the 3 tree strips at the 2 locations (Duke's Plain and Mt Lonsdale) and for each year (2004 and 2005), i.e. 12 combinations. The fitted coefficients have some biological meaning and hence can be evaluated in terms of plausibility and their implications assessed. The relationship was successfully fitted to 11 of the 12 individual tree strip combinations (Table 4.5.2). In fitting Equation 4, the major outlier was Rep 3 in 2005 at Duke's Plain where fitted values for a_1 and b_1 were judged as lacking biological meaning, whilst the values for b_2 and k suggested no change in competitive effects across transect. Thus, analysis of coefficients concentrated on the other 11 tree strips.

The values of 'a_1' indicated potential pasture growth at the edge of the tree strip relative to open pasture at Zone 6. Across the 11 combinations, a_1 ranged from 0.93 to 4.8 with 7 combinations between 1.1 and 2.2 suggesting in most cases a beneficial influence near the tree strip compared to Zone 6. The sign of values for 'b_2' indicated whether potential pasture growth was increasing or decreasing away from the edge of the tree strip. Only two of the combinations had zero or positive sign. Nine combinations had negative sign indicating that the beneficial influence of the tree strip declines away from the tree strip. However, it is not clear from this analysis how far the beneficial effect of a tree strip occurs.

The values for '$1-b_2$' represent the proportion of potential pasture growth at the edge of the tree strip where tree competition might be reasonably, expected to be greatest across the pasture transect. Values ranged from 0 to .52 with the value for overall data being 0.31, i.e. 30% of potential pasture growth.

The sign of the values '*k*' were positive in all cases indicating that, the component of equation 4 representing tree competition (e^{-kx}) declines as distance from the tree strip increases. The magnitude for values of '*k*' represent how slow or rapid the decline occurs across the transect. By calculating the term $x_{0.50} = \frac{-1}{k}\ln(0.5)$ the distance for 50% of the relative tree competitive effect can be calculated ($x_{0.50}$, Table 4.5.2). The distance ($PG_{0.90}$) where the overall competitive effect is reduced to 10% (i.e. pasture growth is 90% of potential) has been calculated as follows from equation 3:

$$0.90 = 1 - b_2\, e^{-k.PG_{0.90}}$$

thus

$$PG_{0.90} = \frac{-1}{k}\ln\left(\frac{1.0 - 0.90}{b_2}\right) \quad \text{(Equation 5)}$$

The values of $x_{0.50}$ indicate that the 50% relative competitive effect for eight of the combinations was less than 1 multiple of tree height. For nine of the eleven tree strip combinations (Table 4.5.2) the overall competitive effect (equation 5) was reduced to 10% at a wide range (0.64 – 8.48) of distances ($PG_{0.90}$) expressed as multiples of tree height.

Figure 4.5.4 shows the equations derived for each of the four location x year combinations (Table 4.5.2). The data set for MTL 2005 (dry year at Mt Lonsdale) subjectively appears to be the most different with lower pasture growth near tree strip and less decline in Zone 6 (at 6-8 multiples of tree height). There was little difference between the equations derived for quadrat data (averaged across tree strip reps) and smoothed data with values calculated for the running mean of four adjacent quadrats sampled along the transect (Appendix 10.7). For four location x year combinations, $PG_{0.90}$ values were between 1.25 and 1.80 x tree height. The overall value of $PG_{0.90}$ was 1.61 x tree height calculated from the equation developed for 4 location x year combinations consistent with soil moisture observation reported in Section 4.4. The 50% relative tree effect was at 0.56 x tree height.

Equation 4 was also tested using distance from the tree strip edge in terms of metres rather than multiples of tree height for the combined datasets at Duke's Plain and Mt Lonsdale. The fitted equation using multiples of tree height explained substantially more of the variation in SDM (47% compared to 30%) further supporting the use of tree height as a basis for assessing impact of tree strips on adjacent pasture.

The trend of declining pasture SDM in the open pasture in Zones 5 and 6 (3 - 8 x tree height) was investigated further. For the combined SDM data from four location x year combinations (DUK2004, DUK2005, MTL2004, MTL2005) there was a significant ($P<.001$) decline across Zones 5 and 6 in pasture SMD (expressed as a % of Zone 6 SDM, y) y = 139 – 5.6 *x*, $R^2 = .260$, n = 86. Where *x* is distance from strip edge in terms of multiples of tree height. However, when data from only Zone 6 were considered, there was a lower rate of decline which was not significant (P = .114) y = 125 – 3.5 *x*, R^2 = 0.053, n = 47. The three combinations, 2004 and 2005 at Duke's Plain and 2004 at Mt Lonsdale, show a significant decline in relative pasture SDM across Zone 6 (y=137.9 – 5.53x, n=40, R^2=0.187, P=0.005), supporting the view that Zone 6 SDM was not at the asymptote of open pasture SDM. In the following analysis of accumulated growth along the whole transect, both possibilities are considered (i.e. decline of SDM through Zone 6, and Zone 6 as a plateau of pasture yield).

At Mt Lonsdale, there was evidence that Zone 6, especially in Reps 1 and 2, could be affected by water movement from outside the exclosures. Nevertheless, in the wetter year 2004, there was a decline across Zones 5 and 6 (Figure 4.5.1c). However, in the drier year 2005 there was more of a plateau across these zones. At this stage of analysis it is not possible, for Mt Lonsdale data, to separate the possible effects of different tree strip attributes, aspects, soil characteristics and water movement. With these caveats, the following analysis examines the implications of the general trends in the SDM data.

4.5.4 Integration of pasture transect

Equation 4 has been used to integrate the effects of a tree strip across a transect from the edge of the tree strip to 8 x tree height. It is important to note that the following integration does not include the width of the strip as the full analysis of tree strip and pasture transect is covered in the following section. The application of equation 4 to the particular sites in this study is also described in a subsequent analysis. The integrated pasture growth has been compared to what would be expected if tree strips were not present. The above analyses suggested that pasture growth was continuing to decline at Zone 6 in Duke's Plain and hence the relative open pasture growth has been calculated as that which would occur at 8 x tree height (0.91, Figure 4.5.3A). A second estimate of relative open pasture growth (1.0) has been made assuming that Zone 6 had no beneficial or competitive effects from the tree strip. Figure 4.5.5 show the integration of tree strip influence as a function of distance from the tree strip for distances up to 4 x tree height. Accumulated pasture growths for both options are similar up to 2 x tree height.

Accumulated pasture growth for the tree strip was calculated using equation 4 and was expressed as a percentage of accumulated pasture growth using the two alternative estimates of open pasture growth as described above (Figure 4.5.6). The results show a 10-20% difference in accumulated pasture growth at a distance of 4 x tree height. These benefits of the tree strip decline as a greater length of transect is considered. This modelling analysis highlights the importance of robust estimates of pasture production in the open without the presence of the tree strip. In this regard, the results from Duke's Plain and Mt Lonsdale are in contrast. The Duke's Plain data (Figure 4.5.1A and 4.5.1B) suggested a decline in pasture growth to a distance of 8 x tree height whilst Mt Lonsdale data suggest a plateau or even a small increase from 5 x tree height (Figures 4.5.1C and 4.5.1D).

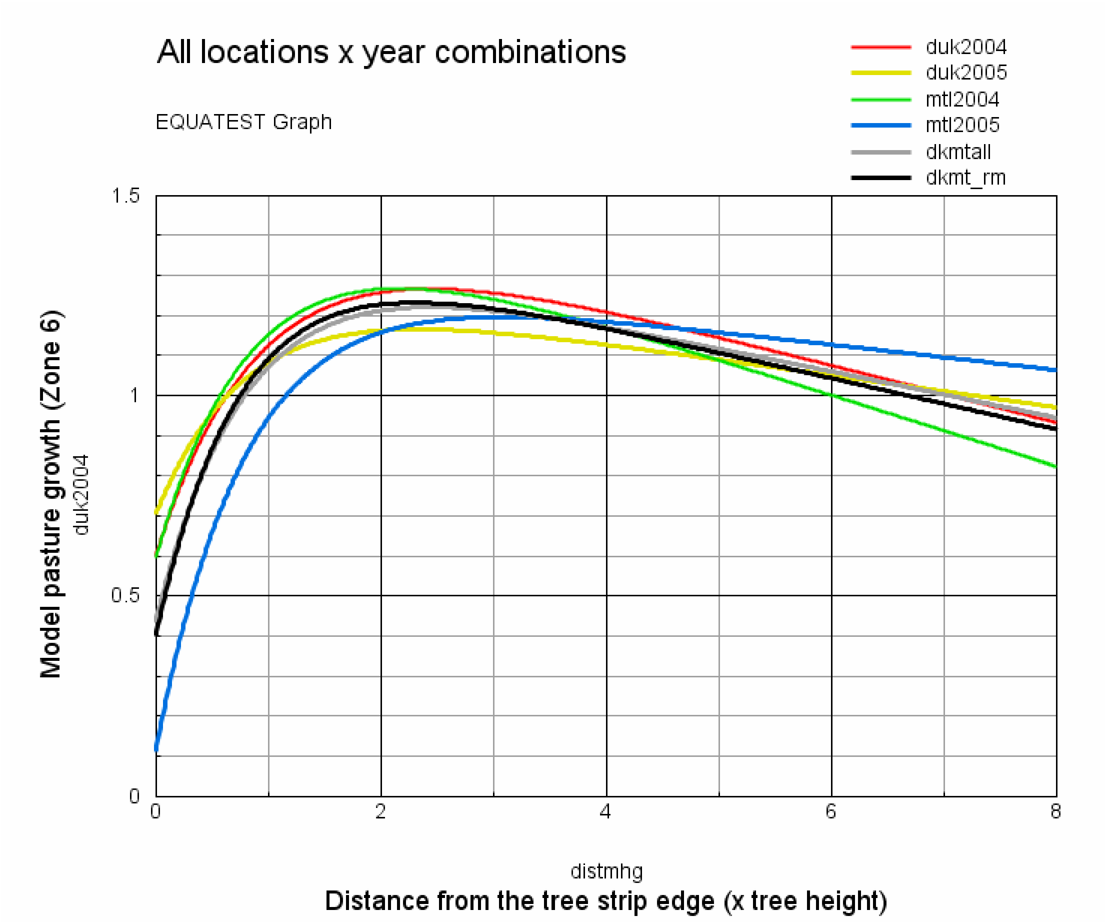


Figure 4.5.4. The relationship between distance from the tree strip edge (in multiples of tree height) and modelled pasture growth expressed as a percentage of Zone 6; i.e. equation 4 fitted for each location by year combination. The coefficients are given in Table 4.5.2 for $y = (a_1 + b_1 x).(1 - b_2 e^{-kx})$. The equation for *dkmtall* uses the coefficients for the four location x year combinations (Table 4.5.2) and the equation for *dkmt_rm* uses coefficients derived from smoothed data (running mean of four adjacent quadrats, Appendix 10.7).

Table 4.5.2. Coefficients for equation 4 $y = (a_1 + b_1 x).(1 - b_2 e^{-kx})$ for different combinations of data from Duke's Plain and Mt Lonsdale. The non-linear regression was fitted iteratively with CoPlot™. $x_{0.50}$ is distance in tree height for 50% of the tree effect. $P_{0.90}$ is the distance at which the competitive component is reduced to 10%.

Location	Year	Rep	a_1	b_1	b_2	$1-b_2$	-k	$x_{0.50}$	$PG_{0.90}$	R^2	n	Comment
Individual tree strip replicates												
Duke's Plain	2004	1	1.221	-0.036	0.692	0.31	-3.025	0.23	0.64	.190	50	
	2004	2	1.143	-0.021	0.707	0.29	-1.551	0.45	1.26	.346	50	
	2004	3	2.503	-0.205	0.667	0.33	-0.432	1.60	4.39	.355	50	
	2005	1	1.501	-0.073	0.482	0.52	-2.396	0.29	0.66	.183	50	
	2005	2	0.984	+0.007	0.530	0.47	-1.579	0.44	1.06	.180	50	
	2005	3				0	≈0.000	xxxx	xxxx	.194	50	Fitted values not sensible
Mt Lonsdale	2004	1	2.191	-0.172	0.799	0.20	-0.306	0.54	6.79	.517	50	
	2004	2	1.641	-0.104	0.554	0.45	-2.090	2.27	0.82	.320	50	
	2004	3	3.623	-0.401	0.785	0.21	-0.243	0.33		.343	48	
	2005	1	1.246	-0.028	1.006	0	-1.585	2.85	1.46	.530	50	
	2005	2	2.149	-0.174	0.832	0.17	-0.735	0.44	2.88	.299	50	
	2005	3	0.701	+0.062	0.972	0.03	-1.945	0.94		.542	48	
	2005	3	0.722	+0.057	0.972	0.03	-1.859			.645	48	Last two values averaged
Average of tree strip replicates												
Duke's Plain Summary	2004	Mean	1.508	-0.072	0.603	0.40	-1.019	0.79	1.76	.419	50	
	2005	Mean	1.290	-0.040	0.455	0.54	-1.214	0.68	1.25	.258	50	
Mt Lonsdale Summary	2004	Mean	1.535	-0.089	0.614	0.39	-1.101	0.57	1.65	.585	50	
	2005	Mean	1.319	-0.032	0.916	0.08	-1.229	0.63	1.80	.694	50	
Duke's Plain and Mt Lonsdale	2004 and 2005	All Means	1.408	-0.058	0.691	0.31	-1.201	0.56	1.61	.477	200	

This relatively simple empirical model (Equation 4) suggests that (a) on average there were benefits from tree strips from 0.5 to 6 x tree height; and (b) provides a basis for the parameterisation of more complex biophysical models such as GRASP which separate the components of tree strip benefits and competition (Section 4.7).

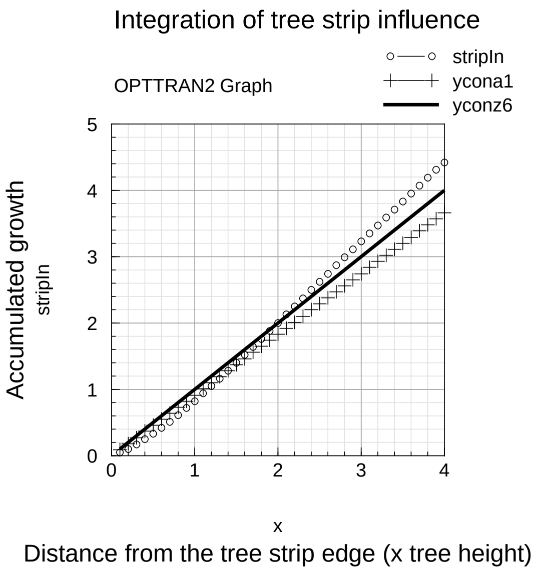


Figure 4.5.5. The relationship between distance from the edge of the tree strip (in multiples of tree height) and accumulated growth for: (a) constant pasture growth (ycona1, +++) assuming that open pasture growth occurs at 8 x tree height; (b) Zone 6 pasture growth (yconz6, solid line); and (c) pasture growth for the tree strip using the integration of equation 4 (stripIn, open circle symbol). Units are multiples of pasture growth in Zone 6.

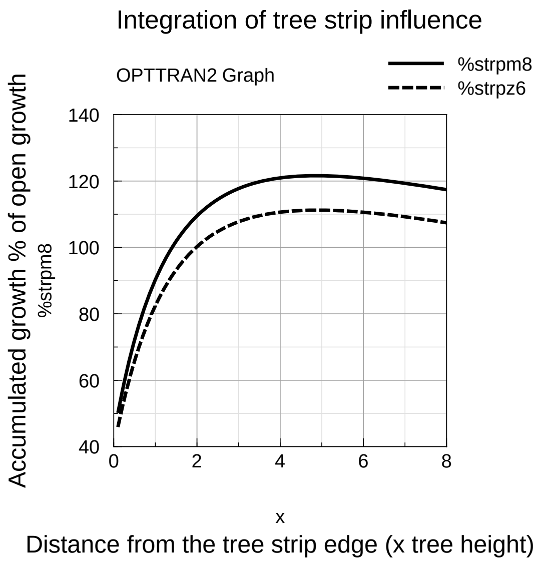


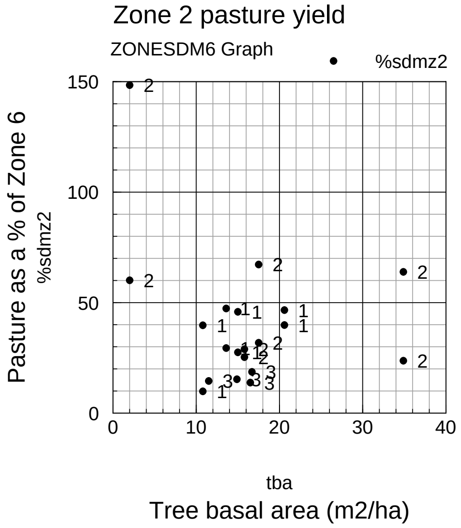
Figure 4.5.6. The relationship between distance from the edge of the tree strip (in multiples of tree height) and relative accumulated growth as a % of: (a) that constant pasture growth that occurs at 8 x tree height (%strpm8, solid line); and (b) Zone 6 pasture growth (%strpz6, dashed line). Accumulated pasture growth for the tree strip was calculated using equation 4 and integrated from the edge of the tree strip. This accumulated pasture growth was expressed as a % of accumulated pasture growth calculated assuming either: (a) pasture growth from equation 4 at 8 x tree height; or (b) Zone 6 pasture growth, namely 1 unit of growth.

4.5.5 Calculation of impact of tree strip on pasture production within the tree strip

The calculation of the overall effect of tree strips on paddock scale pasture production requires inclusion of pasture growth within the tree strip zone (Zone 2). Table 4.5.3 shows pasture growth measured within the tree strip (Zone 2) at the five location x year combinations. For the four combinations (DUK 2004, DUK 2005, MTL 2004, and MTL 2005) used in the pasture zone model described above, Zone 2 was 43% of Zone 6 pasture growth ranging from 28 to 67%. Comparison of Zone 2 pasture growth (as % of Zone 6) with individual tree strips attributes (as documented in Table 3.1.3) indicated a significant correlation with green foliage protected cover (Table 3.1.3, Figure 4.5.7, R^2 = 0.341, n = 15) but not with tree basal area (P = .237). Multiple regression analysis indicated strip width in addition to FPC explained a greater proportion of the variation in Zone 2 (R^2 = .545). However, strip width was regarded as a constant at each location and hence the relationship can not be used to simulate the effect of varying strip widths on paddock pasture production. In addition there are no data on the impact of varying strip dimensions on the pasture zones.

Table 4.5.3. Average pasture standing dry matter within tree strip (Zone 2 compared to Zone 6). At Mt Lonsdale, measured growth in Zone 2 (within the tree strip) was similar in both years despite contrasting rainfall (453 compared to 261mm, Table 3.1.7). High growth occurred at the edge of the tree strip (near a farm road) in both years.

Location	Year	Zone 2	Zone 6	% Zone 2 of Zone 6
Duke's Plain	2004	704	2562	27.5
	2005	1204	2626	45.8
Mt Lonsdale	2004	461	1449	31.8
	2005	431	642	67.2
Mean of four site x year combination				43.1
Moombah	2005	262	1712	15.3



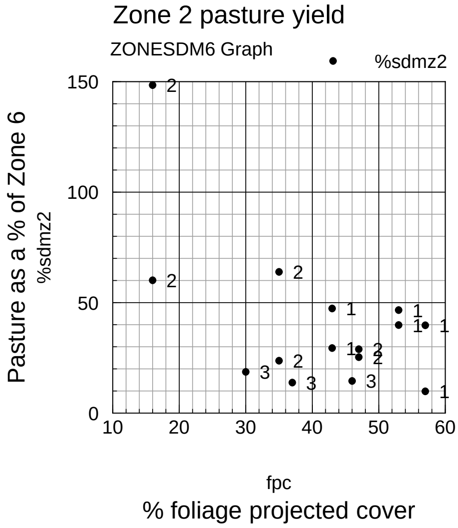


Figure 4.5.7a

Figure 4.5.7b

The relationship between strip (Zone 2) pasture standing dry matter (SDM) and (a) tree basal area or (b) % foliage projected cover. The locations are indicated as (1) Duke's Plain; (2) Mt Lonsdale; and (3) Moombah.

As a more general approach to estimate pasture production within the tree strip (Zone 2), pasture growth data was evaluated in detail. The relationship between distance within tree strip and pasture growth (Figure 4.5.8) was examined using various measures of distance such as (1) distance from middle of the strip; (2) distance from each edge either Zone 1 and Zone 3; (3) absolute distance from strip/pasture edge in metres and multiples of tree height. Because of the high variation in individual quadrat yields, pasture data have been averaged across the three tree strips at each location x year combination.

An effective tree basal area was also calculated at each sampling point in Zone 2 based on the assumption that tree basal area (TBA) was at a maximum (i.e. measured TBA value) in the middle of the strip and half of this maximum value at the edge of the strip. Comparison of these approaches (Figure 4.5.8) indicated that the measure of absolute distance from edge of tree strip best represented the variation in pasture growth within the tree strip for three of the location x year combinations (DUK 2004, DUK 2005, MTL 2005). In the other data sets (MTL 2005, MOO 2005), there was no relationship between pasture growth and quadrat position in Zone 2.

The variation in pasture growth across the tree strips was not necessarily symmetrical. Hence a relationship was developed based on the pasture growth data measured from the middle of tree strip to the edge of Zones 2 and 3 (Figure 4.5.8).

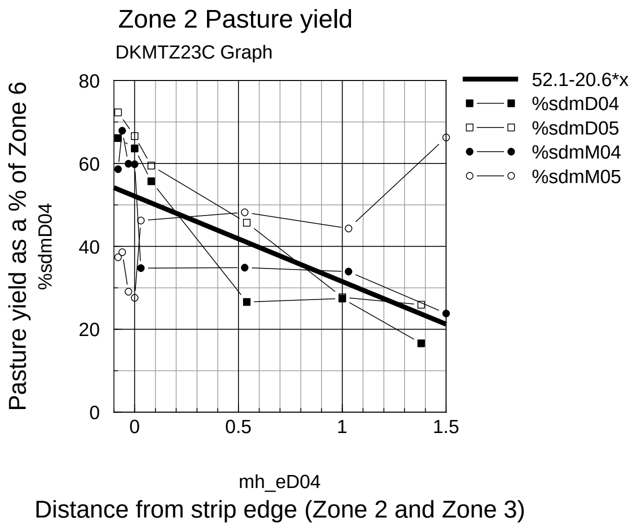


Figure 4.5.8. The relationship between individual quadrat pasture yield within the tree strip (average across 3 tree strips) and expressed as a % of Zone 6 and distance from the edge of the tree strip (i.e. Zone 2 and Zone 3). Distance has been expressed in terms of multiples of tree height. See text for the criteria for selecting the data. Symbols are (a) solid square for Duke's Plain in 2004, %sdmD04, (b) open square for Duke's Plain in 2005, %sdmD05, (c) solid circle for Mt Lonsdale in 2004, %sdmM04, (d) open circle for Mt Lonsdale in 2005, %sdmM05.

The following criteria were used to develop the relationship for Zone 2 to link with the model developed for the pasture zone (previous section). Pasture growth measurements meeting the following criteria were used.

1) location x year combination DUK 2004, DUK 2005, MTL 2004 and MTL 2005 (i.e. excluding MOO 2005 data);
2) transect quadrats from near middle (-0.25 metres) to edge of Zones 2 and 3; and
3) Zone 3 data at distances less than 0.1 multiple of tree height.

Thus this approach concentrated on Zone 2 data specifically adjacent to the pasture Zones 3 to 6 and included some Zone 3 data at the edge (<0.1 multiple of tree height) of the tree strip. Zone 2 pasture expressed growth as a % of Zone 6 (*%pg*) was correlated with distance (expressed as multiples of tree height, *mth*) from edge of Zones 2 and 3. MOO 2005 data are yet to be analysed in detail to understand the different relationship apparent at this location.

%pg = 51.4 – 15.0 *mth* (R^2 = .263, n = 28)   (Equation 6)

A major quadrat outlier occurred in MTL 2005 data set a year of low growth because of low rainfall. In the middle of Zone 2 (at a distance of 1.5 *mth* from edge), *%pg* was 66%. After removal of this outlier, the relationship was

%pg = 52.1 – 20.6 *mth* (R^2 = .453, n = 27)   (Equation 7)

This relationship indicates that pasture growth at 1.3 multiples of tree height into the tree strip (i.e. in these cases near the middle of the tree strip) was 50% of the growth at the edge of Zone 2 and 3.

In the following simulation analysis, a minimum *%pg* of 20% has been suggested as a limit to low pasture growth although the tree strips at DUK and MTL were not wide enough (half width of 1.15 and 1.25 multiples of tree height) to require the use of this limitation. The integration of the Equation 7 for half the width of the tree strip (i.e. half of Zone 2) gave 40% of Zone 6 pasture growth similar to the measured value of 43% for all of Zone 2 at the four location x year combinations (Table 4.5.3).

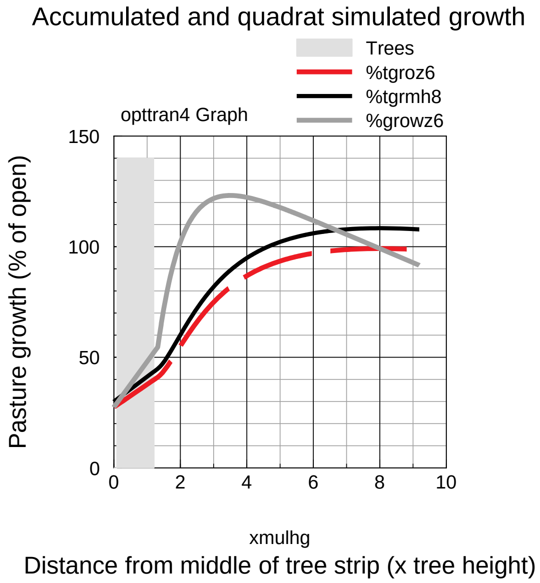
4.5.6 Integration of tree strip effects at a quasi-paddock scale

From a strictly theoretical mathematical viewpoint the two equations (4 and 7 have been used to calculate pasture growth along a transect with the two components of (a) half the tree strip (Zone 2) and (b) the pasture transect (Zones 3 to 6) representing about half the distance between tree strips.

The scale of transect is in multiples of tree height (*mth*). The zero position mth_0 is at the middle of the tree strip, the edge (mth_{23} boundary between Zones 2 and zone 3) is at 1.2 from *mth*. The point of intersection of the two equations was at 0.125 from the edge of Zone 2 and Zone 3 in the pasture transect (i.e. 1.325 *mth* distance from the middle of tree strip mth_0). Thus Equation 7 was used for the tree strip zone (0 to 1.325) and Equation 8 for the pasture transect (repeat of equation 4).

%pg = 100.0(1.427 – 0.064. *mth*) . $1-072e^{-1.282\,(\mathrm{mth})}$ (Equation 8)

Using either Equation 7 or 8, individual ‘quadrat’ pasture growth was calculated for each 0.01 *mth* distance along the transect (Figure 4.5.10). The summation of total transect pasture growth was compared to expected accumulated growth without tree strip and either Zone 6 pasture growth or growth calculated at the transect (*mth* of 9.2 or eight units from edge of tree strip mth_{23}).



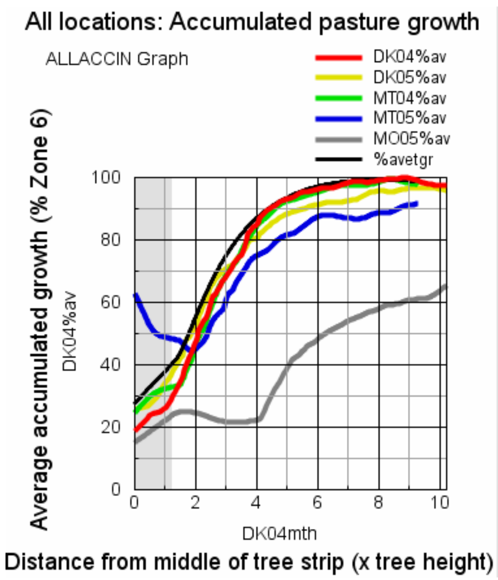


Figure 4.5.10. The relationship between the distance from the middle of the tree strip (in multiples of tree height) and pasture growth as calculated from the empirical model. The %groz6 line is for individual quadrats along the transect simulated by the empirical model (solid grey line). The other two lines are the integration or accumulation of pasture growth expressed either as a % of Zone 6 (%tgroz6, dashed red line) or as a % of growth predicted by the empirical model at 8 x tree height (%tgrmh8, solid black line).

Figure 4.5.11. The relationship between the distance from the middle of the tree strip (in multiples of tree height) and accumulated pasture yield calculated from the interpolation of quadrat measurements of pasture standing dry matter for the five location x year combinations. The individual location x year interpolated values are shown in Figure 4.5.13 and the accumulated values are given in Figure 4.5.14. Duke's Plain 2004 DK04%av; Duke's Plain 2005 DK05%av; Mt Lonsdale 2004 MT04%av; Mt Lonsdale 2005 MT05%av; Moombah 2005 MO05%av; empirical model %avetgr.

For each distance along the transect, accumulated pasture growth has been expressed as 'average' growth up to the indicated distance allowing direct comparison with 'open' pasture growth estimated either as constant Zone 6 (100%) as calculated at *mth* = 8 from Equation 8 (i.e. 91.5%, Figure 4.5.10). The analysis indicated that accumulated pasture growth on the tree strip–pasture transect approached Zone 6 pasture growth at 7 to 9 *mth* (6-8 *mth* from tree edge). Thus the loss of pasture production resulting from tree competition within the tree strip and immediately adjacent to the tree strip (i.e. in Zone 3) was compensated by the beneficial effects at greater distances from the tree strip (i.e. Zones 4 and 5).

Figure 4.5.12 shows the relationship between simulated pasture growth (quadrat and accumulated) and the percentage of open pasture in the transect. For example, at the tree edge, there is zero open pasture, but as a longer transect is considered, then the proportional length of open pasture increases. Figure 4.5.12 shows that accumulated transect pasture growth is equal to 90% of Zone 6 pasture growth where 70% of the transect is open pasture.

The measurements of actual pasture growth were also evaluated in the same way i.e. integration along a transect from middle of tree strip to ≈8 *mth* from edge of strip (Table 4.5.4, figures 4.5.11, 4.5.13 and 4.5.14). Two approaches were used (1) accumulation of individual quadrats; (2) interpolation of each 0.5 metre using adjacent quadrats (Table 4.5.4).

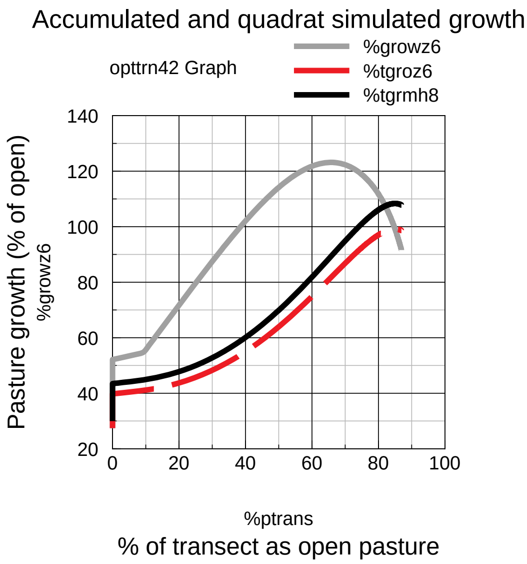


Figure 4.5.12. The relationship between accumulated and quadrat simulated pasture growth (expressed as a % of Zone 6) and the percent of the transect without trees present, i.e. open pasture. The %growz6 line is for individual quadrats along the transect simulated by the empirical model (solid grey line). The other two lines are the integration or accumulation of pasture growth expressed either as a % of Zone 6 (%tgroz6, dashed red line) or as a % of growth predicted by the empirical model at 8 x tree height (%tgrmh8, solid black line).

Pasture data was measured less intensively in the longer Zones 4, 5 and 6 and hence the interpolation approach provides a reasonable alternative to estimate ‘missing’ quadrat data. For the four location-by-year combinations the summation of measured pasture growth data ranged from 75 to 102% of Zone 6, whilst the summation of interpolated data ranged from 92 to 99% (Table 4.5.5).

The mean of the four location-by-year combinations for interpolated was 96% (of Zone 6) compared to 99% (of Zone 6) for the above analysis using Equations 7 and 8. Thus the field data and derived empirical relationship indicated that the overall negative impact of the tree strip on paddock scale (i.e. transect) pasture growth was small (0-5%). Given the minimal impact on pasture growth, the overall value of tree strips should be assessed in terms of other attributes (diet quality, nutrient cycling, hydrology, biodiversity).

Compensation of loss of pasture production due to tree strip

An important question is to what extent the zones of enhanced pasture growth can compensate for the loss of pasture production (relative to open pasture) within and immediately adjacent to the tree strip. To address this issue, we consider an example tree strip 2.5 x tree height wide (e.g. Duke's Plain). For each point along the transect from the middle of the tree strip, we can use the field quadrat data or the empirical model to calculate accumulated pasture growth over an increasing length of transect. By expressing accumulated pasture growth as a percentage of Zone 6 pasture growth, the degree of compensation can be calculated (Figure 4.5.10 and 4.5.11). Field data indicated that accumulated pasture growth was only 50% of open pasture growth at the point on the transect (2.5 x tree length), where the ratio of tree strip to pasture was approximately 1:1. The results of the field data and empirical model showed that accumulated pasture growth had reached 90% of open pasture growth (Zone 6) at a transect distance of approximately 5-7 x tree height from the middle of the tree strip.

A transect of length 5 to 7 multiples of tree height is made up of 1.25 units of tree strip and 3.75-5.75 units of pasture (i.e. 75 to 82% pasture and 25 to 18% tree strip respectively). For 95% compensation, greater proportion of pasture would be required. Other potential benefits associated with the presence of tree strips are likely to offset the loss of 5 or 10% pasture production.

4.5.7 Discussion

Choice of algebraic equation form

In preliminary studies (Appendix 10.7) we examined various algebraic forms to describe the separate beneficial and competitive effects. For example, Scanlan (1992) showed that the separate stimulatory (beneficial) and competitive effects of individual trees could be algebraically represented by different non-linear equations multiplied together to calculate the 'net' effect. The procedure involved fitting six or seven parameters (Appendix 10.7). Scanlan's (1992) field experiments included both live and dead trees and these data were used to fit parameters in a stepwise manner describing stimulation and competition where appropriate.

However, in our tree strip data, it was not possible to independently estimate parameters. The iterative fitting approach of fitting an equation with seven parameters did not provide unique solutions (Appendix 10.7), probably due to high variability in the measured data. Thus a more conservative four parameter model 'constrained linear' was evaluated and assessed in terms of plausibility of fitted parameters, implications for extrapolation, and use in parameterising GRASP. Preliminary testing indicated that the model could be fitted to a wide range of tree strip data (e.g. individual replicates) despite high variability between adjacent quadrats.

The advantage of the algebraic forms used by Scanlan (1992) is that they asymptote (plateau) to an open pasture yield. The following algebraic 'constrained linear' form used in this study does not asymptote and hence in application the fitted relationships have not been extrapolated beyond the length of the sampled transect (8-10 x tree height).

Links of equation coefficients with biophysical processes

The fitted relationship was evaluated for plausibility. The potential benefit (≈40%) at the tree strip edge was consistent with some shading studies. The parameters a_1 (≈ 1.42 represents potential pasture growth (relative to Zone 6) at the tree strip edge and integrates the beneficial effects of trees in terms of shading, shelter, pasture nutrition and soil health. The fitted parameter suggests a potential increase of 40% above open pasture in Zone 6 and perhaps a higher increase when compared to open pasture growth calculated at the end of the pasture transect (8 x tree height). For a eucalypt community at Rockhampton (central Queensland), Scanlan (1992) reported a potential increase of 25-35% in pasture SDM next to tree trunks for small and large trees respectively.

Field experiments (Wilson 1996, Healey *et al.* 1998) involving shading of tropical grasses have shown a similar range of beneficial effects depending on pasture species: 37% in green panic, 22% in rhodes grass, 9% in black spear grass reported by Wilson 1996; and 18% for green panic and creeping blue grass reported by Healey *et al.* 1998. Healey *et al.* (1998) measured a difference in the effect of the type of shade material with a decrease in pasture growth of 10% under ‘bird guard’ in contrast to an increase of 18% under ‘solar weave’. Nevertheless both shading materials resulted in an increase in grass radiation use efficiency (dry matter yield per MJ, 16% and 47% for bird guard and solar weave respectively), highlighting one of the potentially beneficial effects of trees on pasture growth. Thus, the fitted value for a_1 (1.42) in this study is marginally higher than that found in individual tree experiments (1.35, Scanlan 1992) or in shading experiments, but is nevertheless plausible.

Some values for a_1 found using other algebraic forms assuming an asymptote of 100% (Appendix 10.7) were similar (≈ 1.3 or 30% increase above Zone 6 average SDM). However, when algebraic forms that included asymptotes were fitted, values of a_1 were not considered plausible in later GRASP model development (Section 4.7).

Possible effects of soil microrelief and disturbance

The analysis of pasture microclimate (Section 4.4.1) indicated only small effects of tree strips at Mt Lonsdale. The measurements of temperature were taken during the dry year of 2005 and hence, more detailed analysis and modelling are required to estimate effects in the wetter year of 2004 (i.e. the 2003/04 growing season). Thus, the effects of tree strips on pasture growth measured at Mt Lonsdale are likely to be due to other factors in addition to the small pasture microclimate effects.

Thus, the agreement in empirical models between Duke’s Plain and Mt Lonsdale is difficult to explain given the complexity of the biophysical processes that could be occurring at each site. At this stage of analysis, alternative explanations are possible:

1) similar pasture microclimate effects in terms of enhanced pasture growth are occurring despite quite different aspects at the two locations (north western aspects at Duke’s Plain, and eastern aspect for two replicates and western aspect for one replicate at Mt Lonsdale); or
2) the pasture microclimate effects enhancing growth at Duke’s Plain are coincidentally at the same average distance (in terms of multiples of tree height) as the possible effects at Mt Lonsdale of soil water redistribution (Appendix 10.9) and trends in soil texture (Figure 4.3.1).

Implications for grazed situations

The previous analysis concentrated on the exclosure pasture SDM data as a pasture growth bioassay. Whilst pasture growth is important for determining carrying capacity it is not necessarily a good indicator of pasture quality in terms of animal production. Pasture quality attributes such as nitrogen and phosphorus concentrations, digestibility, leaf to stem ratio provide some indication (e.g. Table 4.3.1) of pasture quality. As indicated in the introduction, measurements at other locations have found that pasture quality is greater under trees. Observations of cattle behaviour at Duke's Plain (S. Joyce interview) indicated their preference for pasture within and adjacent to tree strips. However, a consequence of this preference is the risk of higher utilisation in these preferred zones and hence possible changes in pasture species composition to less desirable species, reducing the difference in quality across to the pasture transect.

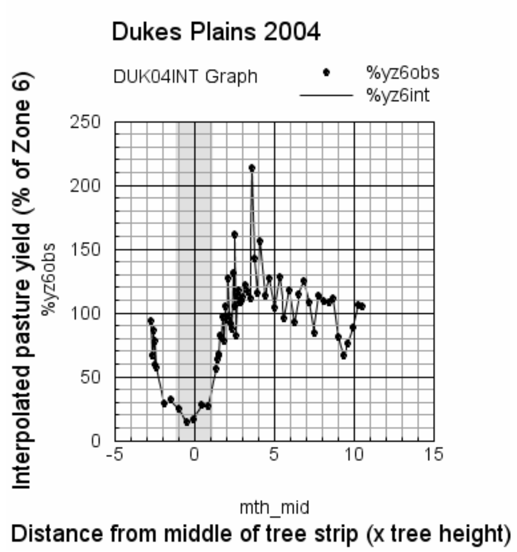
Contributing to the risk of high utilisation under tree strips is the concentration of macropods associated with tree strips. Macropods use tree strips as a protection haven during daylight hours and can provide high grazing pressure even when domestic livestock have been destocked during drought. Thus tree strips, in providing a zone of potentially desired pasture quality and/or an environment attracting concentrations of domestic livestock and macropods, can result in high total pasture utilisation in these areas. Higher utilisation rates in tree strips is likely to exacerbate the competitive effects of trees for water and nutrients leading to a substantial decrease in desirable grass basal area and associated loss of infiltration capacity. Hence, the previous analysis of pasture growth carries the caveat that there are other components of the tree/grass system that must be considered in extrapolating the results in terms of animal production.

4.5.8 Summary and future work

The competitive effects of the tree strip were compensated to some extent by enhanced pasture growth 1-6 x tree height from the tree strip edge (Figure 4.5.3d). As a result, at 5 x tree height (H) distance from the middle of the tree strip, accumulated pasture growth (average along the transect) had reached over 90% of Zone 6 pasture growth (Figures 4.5.10 and 4.5.11). The results suggest that for tree strips 2.4H wide, a distance between tree strips greater than 8H; i.e. 2 x (5 – 1.2) would minimise the overall impact of tree strips on paddock pasture production. Thus the results (Figure 4.5.12) suggest that a configuration of 20% of paddock with tree strips (i.e. 80% open pastures) would achieve at least 90% of open pasture production (i.e. no trees present). However, it should be noted that the loss of 10% pasture production can be quite significant in financial terms when profitability rather than the gross value of production is considered.

Future work

The next steps are to conduct a whole paddock simulation, including the application of the model to Zone 1. The parameterisation of the model also needs to be repeated using alternative algebraic models in terms of representing beneficial and competitive tree effects. The relationship between strip attributes and equation parameters needs to be examined. The effect of year-type on model parameters should also be considered, in particular, the dry year at Mt Lonsdale in 2005. The data from Moombah were not included in this model development as the pasture transect data are yet to be evaluated in terms of the impact of ash beds and different ages of pasture establishment.



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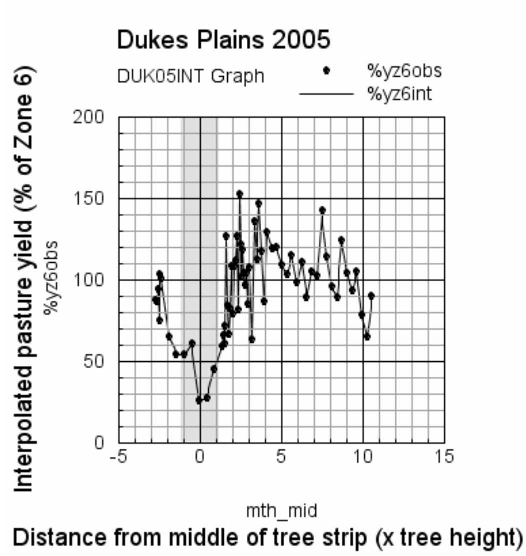

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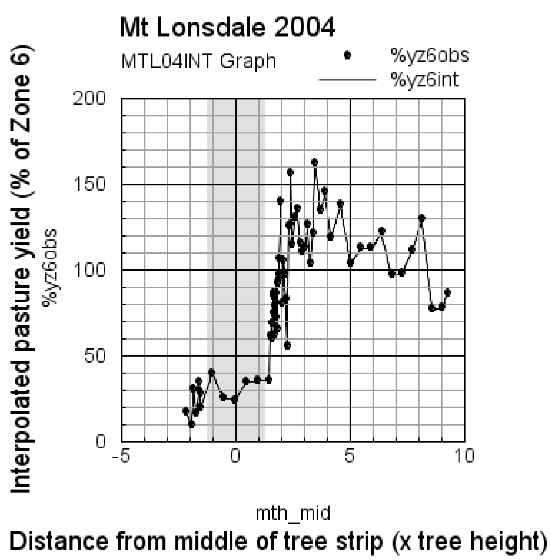

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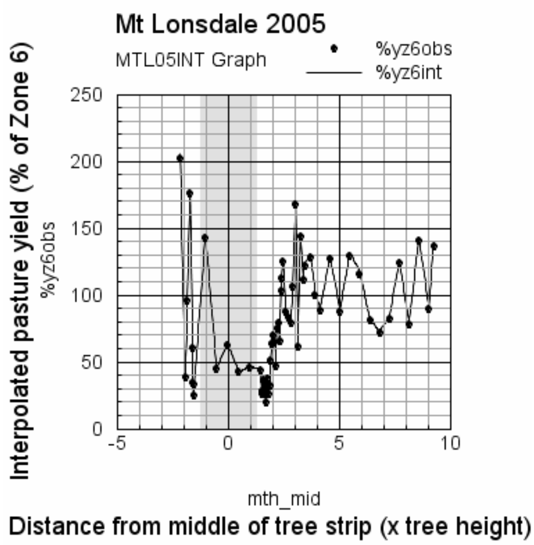

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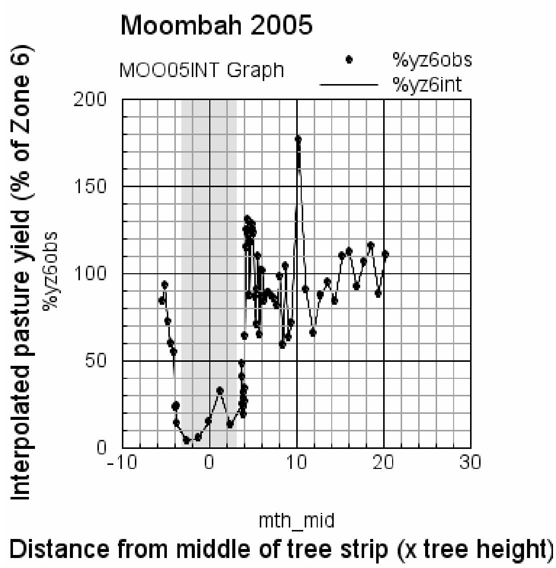
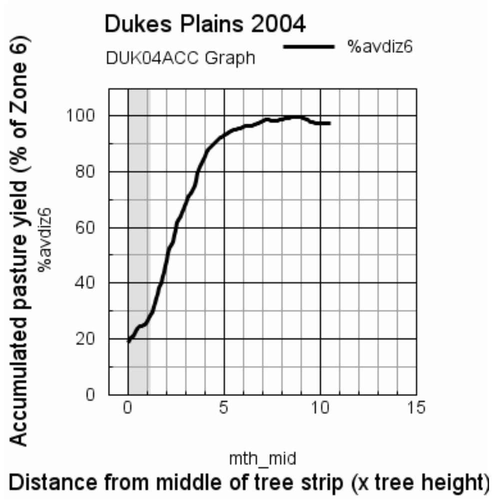


(e)

Figure 4.5.13. The relationship between distance from the middle of the tree strip in terms of tree height and interpolated pasture standing dry matter (yield) expressed as a percentage of Zone 6 for the five location x year combinations. Observed yields (%yz6obs) were linearly interpolated for every 0.5 metres between measurements (%yz6int).



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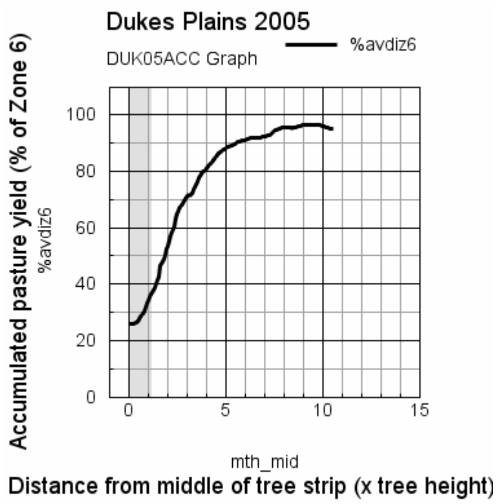

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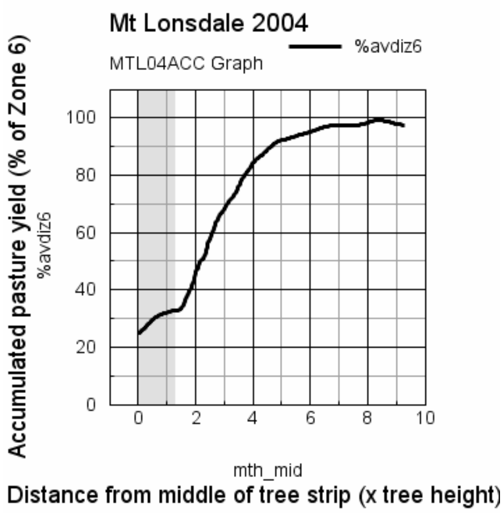

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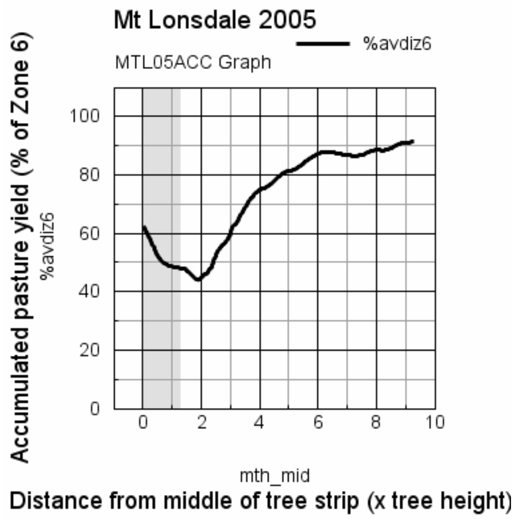

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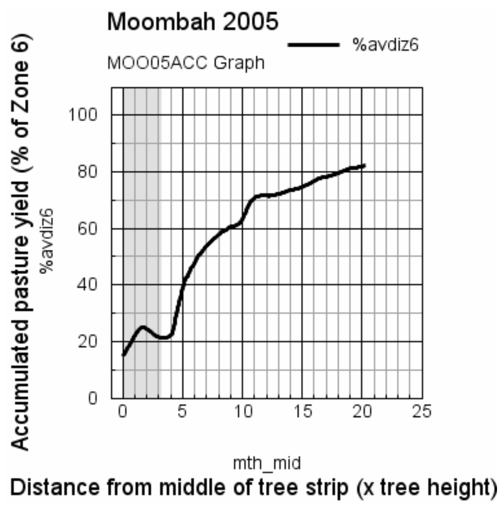


(e)

Figure 4.5.14. The relationship between distance from the middle of the tree strip in terms of tree height and accumulated interpolated pasture standing dry matter (yield) expressed as a percentage of Zone 6 for the five location x year combinations (%avdiz6). Yields were linearly interpolated for every 0.5 metres between measurements as shown in Figure 4.5.12.

Table 4.5.4. Observed and interpolated pasture standing dry matter (kg/ha, % of Zone 6) for each zone along sampled transects. Values from middle of Zone 2 to end of Zone 6 are shown in mid2_6MH.

Study	Location	Year	Zone	No. of Observations	Observed SDM (kg/ha)	No. of Interpolations	Interpolated SDM (kg/ha)	% Observed SDM Zone 6	% Interpolated SDM Zone 6
Duke's Plain 2004									
1	Duk	2004	Zone 1	8	1602.4	23	1118.0	43.7	62.3
1	Duk	2004	Zone 2	6	704.4	31	652.3	25.5	27.4
1	Duk	2004	Zone 3	13	2246.2	13	2246.2	87.8	87.3
1	Duk	2004	Zone 4	11	2982.7	14	2985.4	116.7	116.0
1	Duk	2004	Zone 5	10	3349.2	32	3225.3	126.1	130.2
1	Duk	2004	Zone 6	16	2571.8	61	2557.6	100.0	100.0
1	Duk	2004	mid2_6MH	53	2631.3	122	2521.4	102.3	98.6
1	Duk	2004	all_data	64	2401.5	174	2161.8	84.5	93.4
Duke's Plain 2005									
2	Duk	2005	Zone 1	8	2218.3	23	1909.0	71.2	83.0
2	Duk	2005	Zone 2	6	1203.8	31	1157.0	43.1	45.0
2	Duk	2005	Zone 3	13	2402.4	13	2402.4	89.6	89.9
2	Duk	2005	Zone 4	11	2886.1	14	2856.6	106.5	108.0
2	Duk	2005	Zone 5	10	3091.0	32	3059.9	114.1	115.6
2	Duk	2005	Zone 6	16	2673.4	61	2681.7	100.0	100.0
2	Duk	2005	mid2_6MH	53	2644.4	122	2585.1	98.9	96.4
2	Duk	2005	all_data	64	2525.5	174	2370.7	88.4	94.5
Mt Lonsdale 2004									
3	Mtl	2004	Zone 1	8	333.2	41	342.8	23.9	23.4
3	Mtl	2004	Zone 2	6	461.4	91	448.1	31.3	32.4
3	Mtl	2004	Zone 3	16	1111.4	17	1149.1	80.2	78.1
3	Mtl	2004	Zone 4	17	1605.1	50	1630.7	113.8	112.8
3	Mtl	2004	Zone 5	9	1817.6	108	1756.3	122.5	127.7
3	Mtl	2004	Zone 6	8	1423.0	105	1433.4	100.0	100.0
3	Mtl	2004	mid2_6MH	53	1402.1	334	1397.9	98.5	97.5
3	Mtl	2004	all_data	64	1222.6	412	1204.1	84.0	85.9
Mt Lonsdale 2005									
4	Mtl	2005	Zone 1	8	562.3	41	655.3	98.5	82.6
4	Mtl	2005	Zone 2	6	431.4	91	393.8	59.2	63.4
4	Mtl	2005	Zone 3	16	217.7	17	227.7	34.2	32.0

Table 4.5.4. (continued) Observed and interpolated pasture standing dry matter (kg/ha, % of Zone 6) for each zone along sampled transects. . Values from middle of Zone 2 to end of Zone 6 are shown in mid2_6MH.

4	Mtl	2005	Zone 4	17	612.2	50	649.7	97.6	90.0
4	Mtl	2005	Zone 5	9	759.7	108	743.6	111.8	111.7
4	Mtl	2005	Zone 6	8	680.4	105	665.3	100.0	100.0
4	Mtl	2005	mid2_6MH	53	510.6	334	609.7	75.0	91.6
4	Mtl	2005	all_data	64	519.7	412	604.9	90.9	76.4
Moombah 2005									
5	Moo	2005	Zone 1	8	907.6	69	713.7	41.6	53.0
5	Moo	2005	Zone 2	6	264.9	151	269.6	15.7	15.5
5	Moo	2005	Zone 3	14	1127.7	21	1347.2	78.6	65.9
5	Moo	2005	Zone 4	16	1661.3	68	1614.8	94.2	97.0
5	Moo	2005	Zone 5	10	1530.9	128	1619.0	94.4	89.4
5	Moo	2005	Zone 6	10	1712.5	181	1714.7	100.0	100.0
5	Moo	2005	mid2_6MH	53	1433.7	282	1228.6	83.7	71.6
5	Moo	2005	all_data	64	1307.1	618	1206.5	70.4	76.3

Table 4.5.5. Comparison of observed and interpolated pasture standing dry matter (SDM) for the transect from the middle of Zone 2 to end of Zone 6.

Location	Transect Average SDM (kg/ha)		Zone 6 Average SDM (kg/ha)		Transect % of Zone 6	
	Observed	Interpolated	Observed	Interpolated	Observed	Interpolated
DUK 2004	2631	2521	2572	2556	102.3	98.6
DUK 2005	2644	2585	2673	2682	98.9	96.4
MTL 2004	1402	1398	1423	1433	98.5	97.5
MTL 2005	511	610	680	665	75.0	91.6
MOO 2005	1434	1229	1713	1715	83.7	71.6
Average of DUK and MTL					93.7	97.0
Empirical Model						99.0

4.6 Application of soil water balance – pasture growth model GRASP in modelling the influence of tree strips.

4.6.1 Introduction

The major objectives of the modelling research component in the project were to:

1) develop a version of GRASP that could simulate a transect from tree strip to open pasture;
2) derive parameters along a transect representing the effect of the trees on pasture microclimate and soil and pasture attributes;
3) analyse the individual locations from a modelling perspective; and
4) extrapolate to spatial designs and locations.

The major issue for developing a model of tree effects is to separate the beneficial and competitive effects. To this end, the approach used in this field study has been to collect data along a transect perpendicular to the tree strip (Section 4.2). Data have been collected both at zones along the transect as well as, in the case of pasture yield, every half metre along the transect. The various effects of trees in relation to pasture productivity are summarised in Table 4.6.1 as well as the data sources available to develop models at both a transect and zone scale. From a modelling perspective the outstanding strength of the data set is the measurement of pasture standing matter in mown exclosures along the transect. The weakest components are (a) the lack of site rainfall data; (b) the lack of wind run measurements at two locations (Mt Lonsdale, Moombah) and irregular instrument failure at Duke's Plain, and (c) the lack of historical daily wind run at climate stations for long-term simulations. The following analysis builds on the empirical model developed from transect pasture data as described previously in Section 4.5.

A feature of field experiments addressing tree-grass interactions is that the time involved in measuring key components such as tree water use and tree root distribution is prohibitive given the resources usually available for field projects at semi-remote locations. Thus a major challenge for modelling is to use the data that have been collected to extrapolate the measurements and to fill in the gaps where detailed measurements have not been able to be made (e.g. tree root densities). In this regard the transect measurements of standing dry matter provide a bioassay of the influence of trees along a transect perpendicular to the tree strip. The modelling component of the project aims to interpret this information so as to derive the spatial partitioning of water and nutrients between the tree strip and the pasture components along the transect.

Table 4.6.1. Data Availability for Assessing the Spatial Influence of Trees on a transect or zone basis (x indicates data not collected).

Influence of Trees	Transect	Zone	Comment
Climate			
Rainfall	X	X	Homestead data at each location
Microclimate temperature	X	✓	All locations but install strips
Microclimate humidity	X	✓	
Microclimate wind	X	✓	Only Duke's Plain
Microclimate solar	X	✓	Only one site
Rainfall interception	X	✓	Only one site
Available Water Range			
Soil moisture measurements	X	✓	
Infiltration	Photos	X	Expert Knowledge
Invertebrates	X	✓	
Partitioning of Water Uptake			
Tree strip attributes		✓	Expert Knowledge
Root distribution	X	X	Model Calculation
Isotope ratios	X	✓	Only one location
Soil Fertility			
Soil chemistry	X	✓	
Bioassay (peak N)	X	✓	2005 only
Pasture Growth			
Grass basal cover	Photos	Estimate	Not yet processed
Botanical composition (botanal)	X	✓	
Leaf/stem	✓	✓	
Grass root/shoot partitioning	X	X	Model Calculation
Bioassay Data			
Standing dry matter	✓	✓	
% Green Cover	✓	✓	
Total and litter cover	✓	✓	

4.6.2 Approaches to modelling tree strips with GRASP

4.6.2.1 GRASP computer model: brief description

GRASP is a deterministic, point-based model of soil-water, grass growth and animal production (sheep and cattle), developed and validated for sub-tropical and tropical grasslands (McKeon *et al.* 1990, Day *et al.* 1993, Day *et al.* 1997). A full description of equations and assumptions used in the pasture model is given in Littleboy and McKeon (1997). The model has been calibrated for over 40 pasture communities in Queensland. Soil-water is simulated for given soil attributes (texture and depth) from daily inputs of rainfall, temperature, humidity, pan evaporation and solar radiation. Pasture growth is calculated from transpiration, but also includes the effects of vapour pressure deficit, temperature, radiation interception, nitrogen availability and grass basal area. The effect of variable tree density is simulated by the effects of trees on water use and nitrogen uptake. Animal production responses are calculated by multiple regression equations for live weight change (and wool growth for sheep) as a function of utilisation and length of growing season.

The soil-water model in GRASP is a simple one-dimensional multi-layered tipping bucket model. Infiltration occurs from layer to layer only when the water content of each layer has reached a user-defined field capacity. Four layers are simulated (0-10cm, 10-50cm, 50-100cm and below 100cm. Soil evaporation and pasture and tree transpiration occur from the top three layers. Soil water in the deepest layer (>100cm) is available only for tree transpiration. Before infiltration, run-off is calculated as a function of cover, rainfall intensity and soil-water deficit using an equation derived from measured run-off data (Scanlan *et al.* 1996).

Changes were made to GRASP to allow simulation of soil water and pasture along a transect perpendicular to a tree strip. Previously GRASP assumed that trees are uniformly distributed across the spatial unit (i.e. plot or paddock) being simulated. As a consequence the effects of trees, in terms of water and nitrogen uptake are considered to be uniform across the spatial unit. Typical spatial units to which GRASP has been applied include pasture growth plots (30 x 30m) and grazing trial paddocks (1-100ha). This report describes development of a new version of GRASP that addresses the effects of tree strips and the non-uniform effects of trees across a transect perpendicular to the tree strip. A detailed word model is given in Appendix 10.4.

Three possible modelling approaches were considered in the analysis of the project results:

1) '*Simple*' approach: The effects of trees in terms of competition for water and nutrients were estimated in terms of effective tree basal area. Simulations were compared with the trends in standing dry matter along the transects. This approach assumes no microclimate effects and there were no changes to the relationships in the GRASP model (Appendix 10.6).
2) '*Expert opinion*' approach: Changes in the pasture growth parameters were estimated for the different zones by expert observation. The changes were derived from the opinion of the project's main field operative (W. McGrath and C. Chilcott), colleagues with experience in the measurement and modelling of tree grass interactions and from structured interviews of the grazier collaborators. This approach allows the expert knowledge and observations gained during the project to be represented in parameter sets and tested with the measurements taken along the transect with the outcomes of the interviews also documented (Appendix 10.5).
3) '*Model modification and calibration*' approach: Key pasture growth and tree water use parameters were derived from the empirical model developed in Section 4.5. Climate inputs as measured at different zones (Section 4.1) along the pasture transect were used to estimate daily climate data along the transect. Thus this approach uses some of the measurements of the climate and model pasture components to derive model parameters.

Preliminary work was conducted on the *simple* and *expert opinion* approaches and is described in detail in Appendix 10.6. The results from these two approaches indicated that the beneficial effect of tree strips through their likely impact on pasture microclimate was not represented adequately. As a consequence, greater effort was placed on the development of a more sophisticated parameterisation of tree strip effects (as detailed in the following section).

This section contains over 140 graphs. To maintain the integrity of links to source data files the file name of each CoPlot™ draw file and column captions have been included. These will be removed in final publication but have been retained here to allow rapid response to review and updated analyses.

The expected outcomes of these modelling analyses were:

1) better representation of the effects of tree strips;
2) a formal test of previous hypotheses on how tree strips affect pasture production; and
3) capability to extrapolate field results to other years and locations.

4.6.3 Modelling tree strip effects at Duke's Plain

The following section describes the representation of effects of the tree strip on climate inputs and GRASP parameters along the pasture transect at Duke's Plain. The issues include:

1) representation of tree strip attributes;
2) pasture growth parameters;
3) tree root parameters;
4) grass basal cover;
5) daily climate of the pasture layer including solar radiation interception, wind and potential evapo-transpiration;
6) limitations to model representation; and
7) extrapolation over time and to other sites.

The following analysis is based on the assumption that the beneficial and competitive effects of tree strips along pasture transect can be represented in terms of model parameters describing pasture microclimate, tree water and nutrient uptake, pasture growth and senescence, nutrient availability and efficiency of use by pasture, and soil moisture characteristics. As indicated earlier, some of the effects associated with a tree strip may be the result of systematic mechanical disturbance of soil and vegetation debris and/or variation in soil features affecting hydrological processes parallel with the tree strip. The soil water – pasture growth model GRASP can be parameterised to account for some of these systematic effects, e.g. localised nutrient availability, and runoff and runon areas. However, this level of detail of measurement is not available in this project and hence the following study concentrates on representing the general competitive and beneficial effects of tree strips.

As stated previously the approach adopted in this section has been based on the results from the empirical model (Section 4.5) and the analysis of climate data (Section 4.1). A FORTRAN program (DUK82.FOR) was developed to estimate GRASP parameters at each quadrat sampling point along the pasture transect.

4.6.3.1 Representation of tree strip attributes along pasture transect at Duke's Plain

Assumptions of main tree strip effect along the transect

The transects of pasture growth commenced at the edge of Zone 1 furthest from the tree strip. Zone 2 was within the tree strip and Zones 3 to 6 contributed the main pasture transect to be simulated. The competitive effects of trees through water and nitrogen uptake were assumed to be symmetrical on either side of the tree strip i.e. the same algebraic form away from the edge of the tree strip into both Zone 1 and Zone 3 (and beyond). Similarly the shading effect of trees on solar radiation received by pasture layer was assumed symmetrical on either side of the tree strip (as discussed later important exceptions are the tree strips at Moombah where tree strip orientation was east-west). For the purpose of a general transect model, Zone 1 was assumed to be upwind as was the case at Duke's Plain where Zone 1 wind run was generally greater than Zone 3 and Zone 6 wind runs (Figure 4.1.5). As indicated previously in several cases, Zone 1 pasture data have to be treated with caution given the historical preference of using this zone for vehicle movement and other possible disturbance.

Tree basal area

Figure 4.6.1 shows the different attributes of the tree strip and pasture transect in terms of identified zones, tree basal area, foliage projected cover and distance from edge in terms of metres or multiples of tree height. Tree basal area (Figure 4.6.1b) has been estimated based on the preliminary assumption that, for relatively narrow tree strips, measured values (Tables 3.1.3 and 3.1.4) represent the middle of the tree strip, and that tree basal area at the edge is 50% of the value at the middle of the tree strip. A more detailed model of relative tree basal effects across the tree strip should be developed in the next stage.

Tree strip effects: beneficial and competitive indices

Figure 4.6.2 shows the key components of the beneficial and competitive effects of trees as used in the following parameterisation. The change in potential growth index derived from the empirical relationship (Equation 4, Section 4.5) was applied from the edge of the tree strip (Zones 2 and 3) to 8 x tree height (end of Zone 6; Figure 4.6.2a). As a first example potential growth index was given by the equation $y = (a_1 + b_1 x)$ where a_1 = 1.427 and b_1 = -0.064 (Table 4.5.2). Other coefficients (Table 4.5.2) or forms of equations (Appendix 10.7) could be tested in the transect model developed here.

The tree strip itself (Zone 2) was assumed to have the same potential growth index as at the edge. We hypothesise that the beneficial effects are linked to the improved pasture microclimate such as occurs with wind breaks (Cleugh *et al.* 2002). Thus Zone 1 (up wind) is treated differently to Zone 3 (down wind). In Zone 1, potential growth index has been interpolated between the edge of the tree strip and the assumption that the beneficial effect finishes at 1 x tree height. Beyond this point (i.e. further away from the tree strip) Zone 1 is assumed to be the same as at the end of the pasture transect in Zone 6. As indicated in Section 4.1, wind direction is variable and hence, a more detailed model of daily climate along the transect should be developed in the next stage.

The competitive components are shown in Figures 4.6.2b and c with declining competitive effect away from both edges of the tree strip. The components of Equation 4 (Section 4.5) that describe the tree competition effect are 1) the overall tree competition index on pasture growth $(1-b_2e^{-kx})$, Figure 4.6.2b; and 2) the tree competition effect relative to Zone 2, namely e^{-kx}, Figure 4.6.2c. From Table 4.5.2, b_2 = 0.721 and k = 1.282.

The overall tree competition effect (Figure 4.6.2b) can be combined with the effective tree basal area (Figure 4.6.1b) to give an index of the interaction of both tree density and tree competitive effects from Zones 1 to 6. The interactive index (Figure 4.6.2d) is used in a later section to estimate grass basal area.

The parameters describing beneficial and competitive effects of trees relate to different processes namely pasture growth and tree water/nitrogen use respectively. The coefficients used in the initial analysis of the pasture transect were derived from Equation 4 fitted with smoothed (i.e. running mean) data from Duke's Plain and Mt Lonsdale (Appendix 10.7). The coefficients provided a slightly greater separation of the beneficial and competitive effects of tree strips in Zones 3 to 6 than the empirical model fitted to individual quadrat data. The overall equation was very similar to that fitted with actual quadrat data (Figure 4.5.4).

Tree strip effects on pasture growth parameters

Figure 4.6.3 shows the application of the potential growth index to the key pasture growth parameters used in GRASP. The values used for an average native pasture (McKeon *et al.* 1998) have been modified as shown in Figure 4.6.3: potential pasture regrowth rate (per unit of grass basal area, p006); transpiration use efficiency (p007); radiation use efficiency (p008); and evapo-transpiration efficiency (p288) used to calculate grass basal cover. The parameters which describe the dilution of nitrogen and the effect on plant growth were also modified. In the case of the nitrogen concentration at which growth stops (p101) the open pasture parameter was divided by the potential growth index, i.e. a lower value of p101 allows for greater growth when nitrogen is limiting.

Table 4.6.2. Nitrogen concentration and yield at Duke's Plain, Mt Lonsdale and Moombah measured in May 2005. The low values at Mt Lonsdale are the result of a dry year and low pasture growth.

Zone	% N Concentration			N Yield (kgN/ha)		
	Duke's Plain	Mt Lonsdale	Moombah	Duke's Plain	Mt Lonsdale	Moombah
1	0.62	1.13	1.68	14.7	7.5	15.9
2	1.02	0.92	1.18	12.5	3.9	3.1
3	0.90	0.91	1.35	21.4	2.1	13.1
4	0.54	0.69	1.36	17.0	3.5	22.7
5	0.58	0.68	1.36	18.5	5.5	20.0
6	0.70	0.67	1.45	18.8	3.8	23.9

The hypothesised relationship given in Figure 4.6.3e is supported by the observed nitrogen concentration data collected at Duke's Plain in 2005 in Zones 1, 4, 5 and 6 (Table 4.6.2). The high concentrations observed in Zones 2 and 3 probably reflect the lack of water available for pasture growth and hence there has been less dilution of nitrogen uptake. The observed data suggests that greater dilution of available nitrogen occurred in Zones 4 and 5. Zones 4, 5 and 6 had similar nitrogen yield, suggesting little impact of distance from the trees on available nitrogen. Zone 3 had slightly higher nitrogen yield (21kgN/ha) suggesting a possible influence of the tree strip on soil fertility as would be expected with leguminous Brigalow trees. Given the high variation in measuring N yield, in the following simulations, potential nitrogen uptake was assumed to be a constant average of Zones 3 to 6 namely 19kgN/ha. A value of 0.60%N was assumed for open pasture (average of Zones 4, 5 and 6). Based on other modelling studies (G. McKeon, unpublished data), lower values of minimum %N have been assumed for Zone 2 (within the tree strip). These studies suggest that better potential growing conditions (diffuse length, low VPD) result in lower minimum %N.

Tree strip effects on spatial tree root distribution

Figure 4.6.4 shows the components of tree root density for four soil layers (0-10cm, 10-50cm, 50cm-1m and 1m-2m) as calculated from the relative tree competition index (Figure 4.6.2c) and relative tree root parameters derived for Zone 2 for a maximum tree rooting depth of 2 metres. The 'effective' tree basal area, described previously, was calculated as the multiplication of tree basal area and the competition index (Figure 4.6.1b and Figure 4.6.4e). Alternative rooting patterns could be represented including root pruning. These patterns could be derived from more detailed analysis of soil water measurements described in Section 4.4.

The effects of tree strips on pasture senescence, i.e. death of green pasture tissue, occur through shading interactions with soil water stress and frost. The parameters include 1) the minimum temperature at which 100% death occurs due to frost (p011); and 2) the soil water index required for 100% green cover (p009). In the following simulation the value for frost sensitivity have been set constant. As described later preliminary tests indicated that better simulation of observed green cover could be obtained by changing these relationships across the tree pasture transect.

Tree strip effects on grass basal area

The pasture model GRASP uses estimates of pasture (grass) basal area (GBA) to calculate pasture growth at the start of the growing or regrowth after heavy defoliation. In ungrazed situations, GBA is correlated with pasture standing matter at the end of growing season. Dynamic models of GBA have been developed either as a function of growing season evapo-transpiration or simulated SDM at end of growing season. These modelling approaches allow the impact of varying tree density on GBA to be calculated. Heavy utilisation combines with drought (low soil water) to greatly reduce GBA (Scattini 1973, Orr *et al.* 1993, McKeon *et al*. 2004). The observed grazing preference of cattle for pasture within the tree strip is likely to reduce GBA in Zones 1, 2 and 3. Whilst not explicitly measured in this project, observations by project operatives (W. McGrath) show lower GBA in these Zones, especially Zone 2 (the tree strip) emphasising the importance of correctly estimating GBA in spring 2003, at the time of grazing exclosure, and spring 2004 after the first year of exclosure.

Thus a dynamic approach based on water availability and grazing history was used to estimate GBA in spring 2003 and 2004. The following steps were used to calculate grass basal area for each year using the following assumptions:

1) Relative grass basal area was assumed to be proportional to available moisture for pasture growth, namely (1- relative effective tree basal area) as described above; *gba index 1* = (1-(treecompix*tba)/tbamax) (Figure 4.6.6a);
2) Under grazing, the effect of drought and moisture stress is assumed to be greater on grass basal area than on pasture growth (McKeon *et al*. 1990; McKeon *et a*l. 2004); thus *gba index 2* = α*x/(α*x+1-x) where x is *gba index 1*; the value of α used is 0.5 (Figure 4.6.6b). However, the interaction of moisture

stress due to tree competition, the benefits of shading, and the impact of grazing are not clear cut (e.g. Scanlan 1984; p.108) and will require further evaluation;

3) The relative grass basal area was converted to % units by multiplying by water use efficiency which varies across the transect (Figure 4.6.3d); *gba index 3* = p288**gba index 2* (Figure 4.6.6c);
4) An estimate of grass basal area in open pasture was given by an estimated pasture yield of 2500kg/ha ÷ 500 = 5%; *gba* in open pasture = 5%;
5) The grass basal area in the second year following exclosure was calculated relative to grass basal area in the open pasture; *gba* in 2004 = *gba* in open pasture x (*gba index 3*/p288) (Figure 4.6.6d);
6) The grass basal area in the first year, which included the effects of previous grazing was estimated as 0.5 of the grass basal area estimated in the ungrazed situation; *gba* in 2003 = 0.5**gba* in 2004 (not shown); and
7) The calculated grass basal area in 2005 showed a very similar pattern to that 1) estimated from expert opinion (W. McGrath) (Figure 4.6.6e); and 2) calculated from observed standing dry matter averaged over the two years (SDM ÷ 500) (Figure 4.6.6f). Components of the above procedure in deriving these estimates of grass basal area are shown in Figures 4.6.7a-d. The residual yield (kg/ha) at the time of mowing pasture was assumed to be proportional to grass basal area (%) estimated at the start of each growing season (Figures 4.6.7e and f). Residual yield = 75**gba*.

Tree strip effects on climate: wind and solar radiation

As indicated earlier, Zone 1 is assumed to be upwind and hence the data for wind run are more likely to represent open pasture than other zones. From the measured wind data at Duke's Plain Zones 2, 3 and 6, ratios of wind run (km/day) to Zone 1 were derived (0.5, 0.4 and 0.6) (Figure 4.6.8a). As discussed previously (Section 4.1), data from Zone 4 was not considered reliable enough for inclusion in this parameterisation.

The proportion of solar radiation intercepted from the tree strip was calculated from the relationships following J. Carter (personal communication). Foliage projected cover (%*fpc)* was calculated from maximum tree basal area in Zone 2 (TBAz2): *fpc* = (0.0 + 3.104 * TBAz2 - 0.00047 * TBAz2 ** 3). If tree basal area was greater than 44 m^2/ha, then *fpc* was set to 97%. The proportion of solar radiation intercepted (*psolarinterc)* was calculated from *fpc: psolarinterc*=0.01*0.93**fpc.* It was assumed that the proportion of solar radiation intercepted is zero at a distance of 1 x tree height from the edge of the tree strip (Figure 4.6.8b). The inclusion of shade models is likely to improve the parameterisation of effects on solar radiation interception especially when effects throughout the day are considered. The calculation of shading throughout the year will require a far more sophisticated model than this initial representation particularly for summer afternoons when strip orientation can have a large impact. The representation used here is regarded as only an initial attempt.

Tree strip effects on climate: pan evaporation

GRASP uses Class A pan evaporation to calculate potential evapo-transpiration. Data from six stations in Southern and Central Queensland (2000-2005) were used to estimate the effects of wind run on pan evaporation for summer (October-April) growing seasons. A previously developed multiple regression (given below) based on vapour pressure deficit (VPD) and solar radiation accounted for 59% of daily variation across the locations. The addition of windrun (km/day) accounted for 65%, i.e. an additional 6%. Thus the relationship (figure 4.6.9) reflects the relatively small effect that wind has on measured Class A pan evaporation compared to the effects of VPD and solar radiation. The following steps were used in the calculation:

1) average wind for the locations was 118.26 km/day;
2) wind at each point on the transect was calculated based on the proportions indicated in Figure 4.6.8a;
3) Class A pan *in the open* was calculated from the multiple regression pan = -0.481 + 0.1694 VPD (hPa) + 0.1637 Solar-radiation (MJ/m^2) derived previously from the SILO surfaces for the same region; and
4) At each point on the transect, the proportion of Class A pan *in the open* was calculated as 0.01*(72.8+0.23*wind) (Figure 4.6.9).

A tree climate impact index (groclix) was calculated by adding the hypothesised impacts of wind, pan evaporation and solar radiation interception. The relationship was developed from a multi-regression of potential growth index and *psolarinterc* and *pepan*. In a sensitivity test (results not reported), a tree climate impact index was evaluated as an alternative approach to modifying pasture growth parameters. Further research is warranted on this approach once a further physiological review has been conducted.

The following simulation study used the wind run measurements at Duke's Plain to parameterise a general asymmetrical effect of the tree strip on wind run and calculated pan evaporation (Figure 4.6.8). Variation in wind direction, synoptic conditions, tree strip orientation are all likely to influence the spatial distribution of tree strip influences and hence a caveat on the following simulations is that they are specific to the effects on wind run measured at a single Duke's Plain tree strip in 2004.

Tree strip effects on climate: rainfall interception

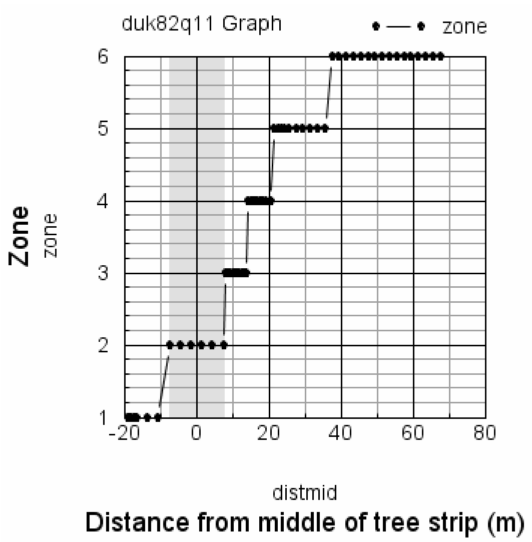
Rainfall interception in Zone 2 was calculated from Carter's derived understorey microclimate model from the measurements of A. Pressland. Interception = a*(RAIN**b)*(*tbaz*2**c) where a = 0.046; b = 0.785; and c = 0.761. Rainfall interception is the minimum of the above calculation and pan evaporation + 2mm. For GRASP, a proportion of rainfall interception is calculated and converted to a multiplier of summer and winter rainfall (p065 and p241 respectively), (Figure 4.6.10). In the initial model, the average effect of interception for a season is represented. In the next stage, calculation of interception should vary with daily rainfall amount.

Tree strip effects on climate: temperature

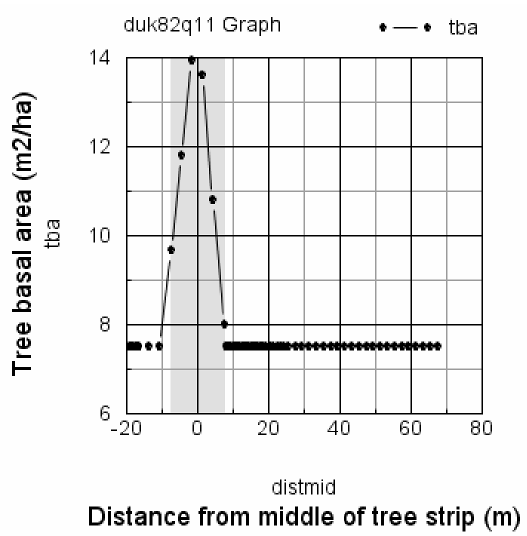
The effects of the tree strip on Zone temperatures (maximum, minimum and dewpoint) were derived from the measurements at Duke's Plain. Values used were from a preliminary analysis of the temperature data and represent a conservative view of the impact of tree strips. The analysis should be repeated once the relationship between daily wind direction and temperature change across the transect has been derived. In the case of temperature, Zone 6 was assumed to more accurately represent open pasture temperatures than Zone 1, and hence the changes have been calculated from Zone 6 measurements (Figures 4.6.9c, d and e). Humidity data were not collected at Duke's Plain and hence the change in dew point was assumed to be the same as occurred in minimum temperatures.

Table 4.6.3. Climate and derived pasture growth indices of each growing season at Duke's Plain. The values are for last quadrat of pasture transect of Zone 6 (87m on the transect). Tree transpiration* is given for Zone 2.

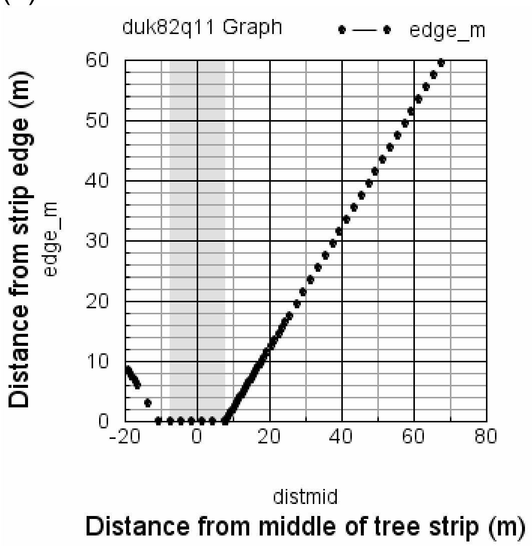
	2004	**2005**
Days from reset (July) to harvest (May)	299	308
Rainfall (mm)	503	559
Rainfall (mm/day)	1.68	1.81
Evapo-transpiration at end of transect (mm/day)	1.64	1.52
Pasture transpiration (mm/day)	0.87	0.70
Tree transpiration* in Zone 2 (mm/day)	0.86	0.78
Vapour Pressure Deficit (hPa)	18.46	19.08
Class A Pan(mm/day)	6.11	6.22
Pan at end of transect (mm/day)	5.72	5.82
Soil water index (0-1)	0.633	0.532
Temperature index (0-1)	0.715	0.705
Radiation (MJ/m^2/day)	21.19	21.19
Growth Index (0-1)	0.41	0.40
Simulated seasonal growth rate (kg/ha/day)	9.27	7.54



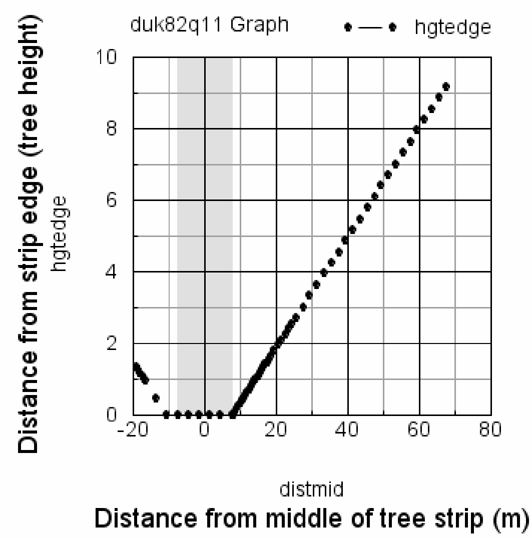
(a)



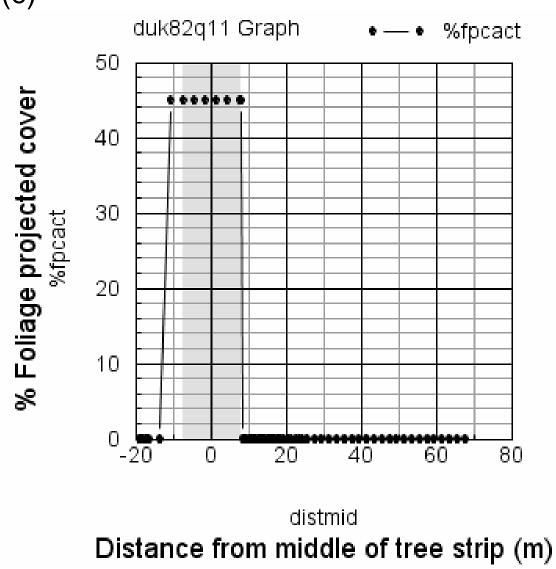
(b)



(c)



(d)



(e)

Figure 4.6.1 Relationship between distance from the middle of the tree strip and attributes of the pasture transect: (a) Zone; (b) tree basal area used in the transect simulation; (c) distance from edge of tree strip; (d) distance from edge of tree strip in multiples of tree height; and (e) estimated foliage projected cover from tree basal area.

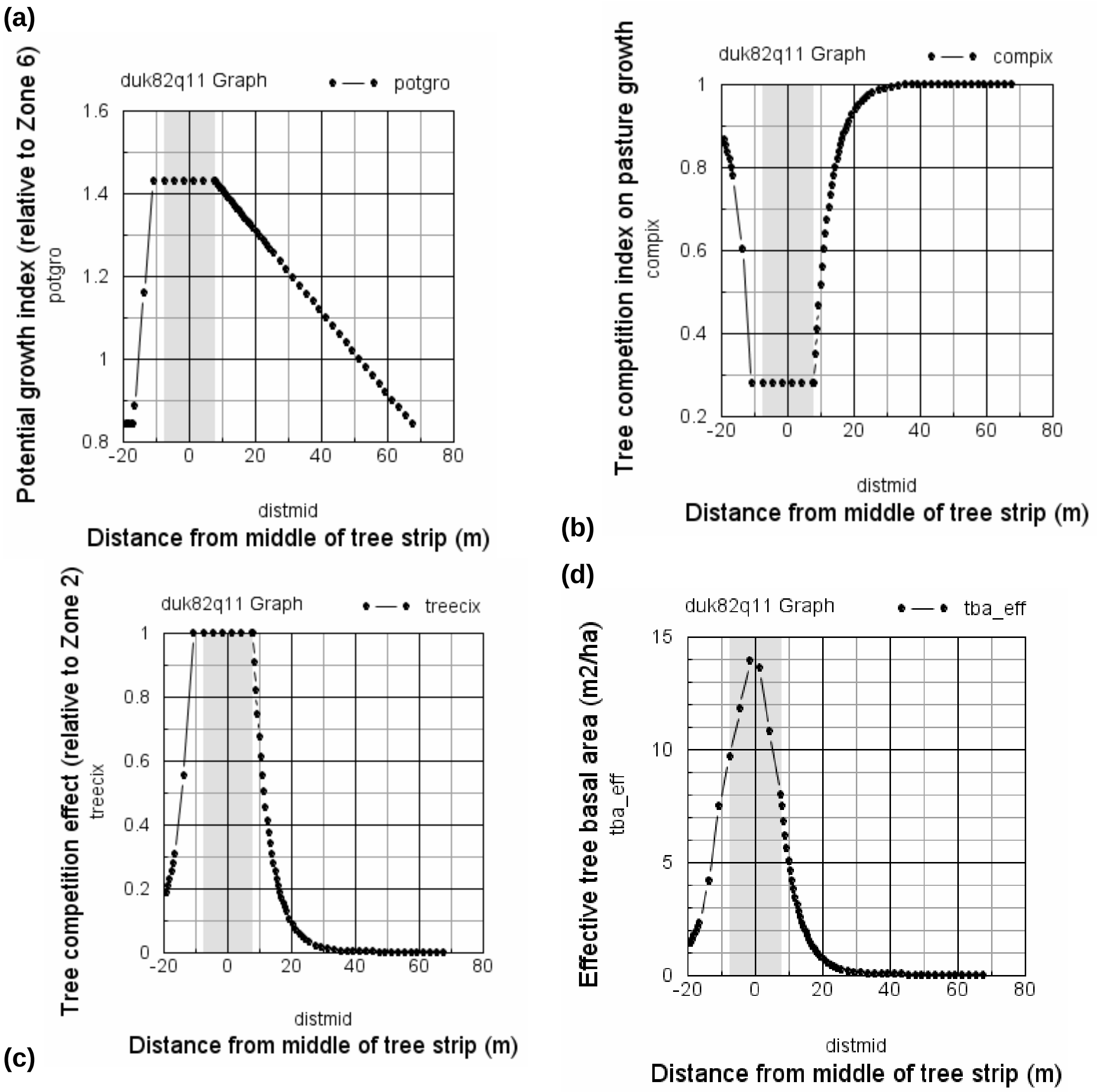


Figure 4.6.2. Relationship between distance from the middle of the tree strip and attributes of the pasture transect: (a) potential growth index relative to Zone 6 used to modify growth parameters; (b) relative tree competition index on pasture growth; (c) competitive effect of trees relative to Zone 2; and (d) effective tree basal area calculated as the multiplication of tree basal area in Figure 4.6.1b and tree competition effect (Figure 4.6.2c).

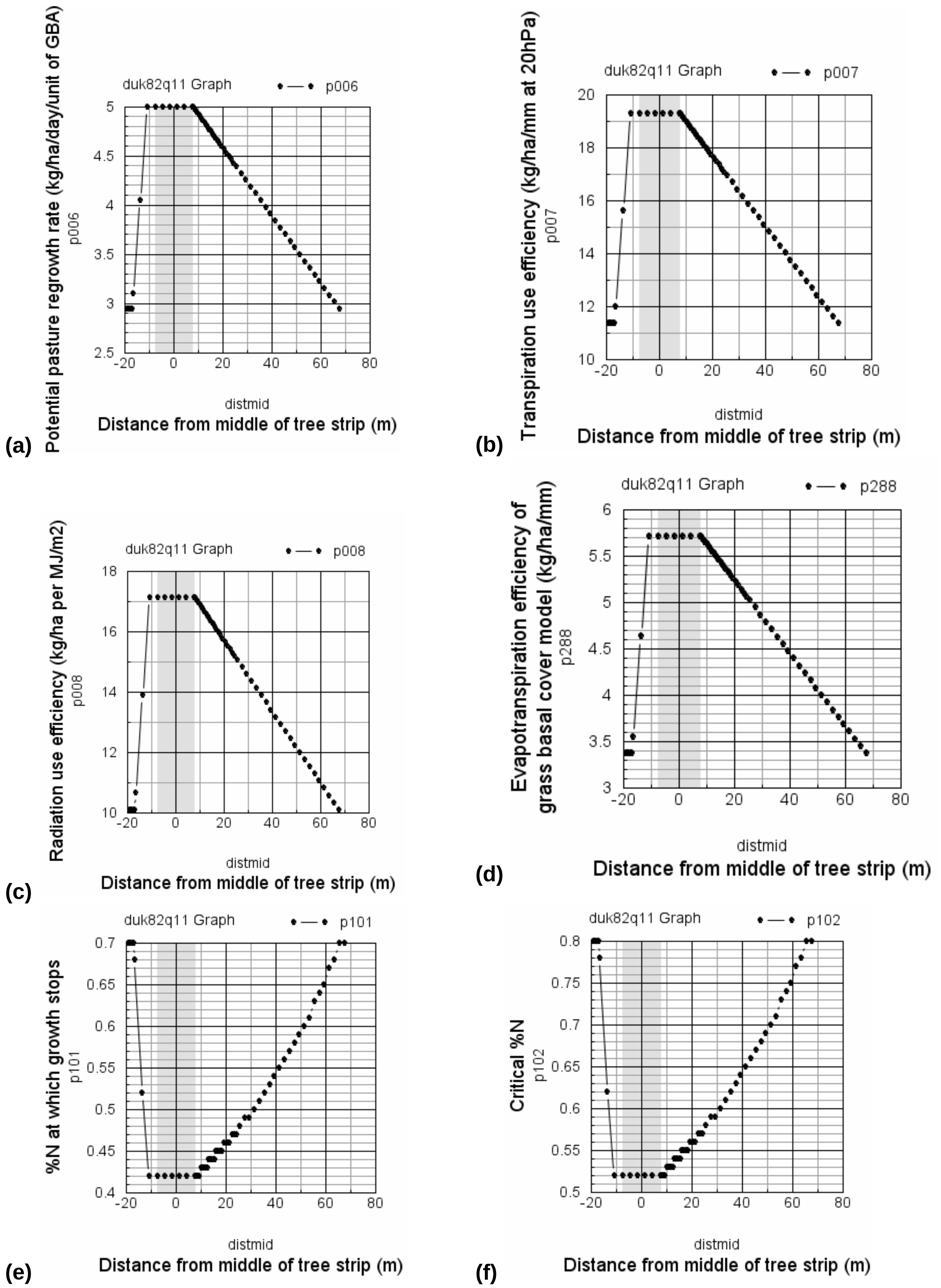


Figure 4.6.3. Relationship between distance from the middle of the tree strip and model parameters along the transect: (a) potential pasture regrowth rate; (b) transpiration use efficiency; (c) radiation use efficiency; (d) evaporation use efficiency used the grass basal area model; (e) percent nitrogen at which growth stops; and (f) percent nitrogen at which effect of nitrogen limitation begins (critical % N).

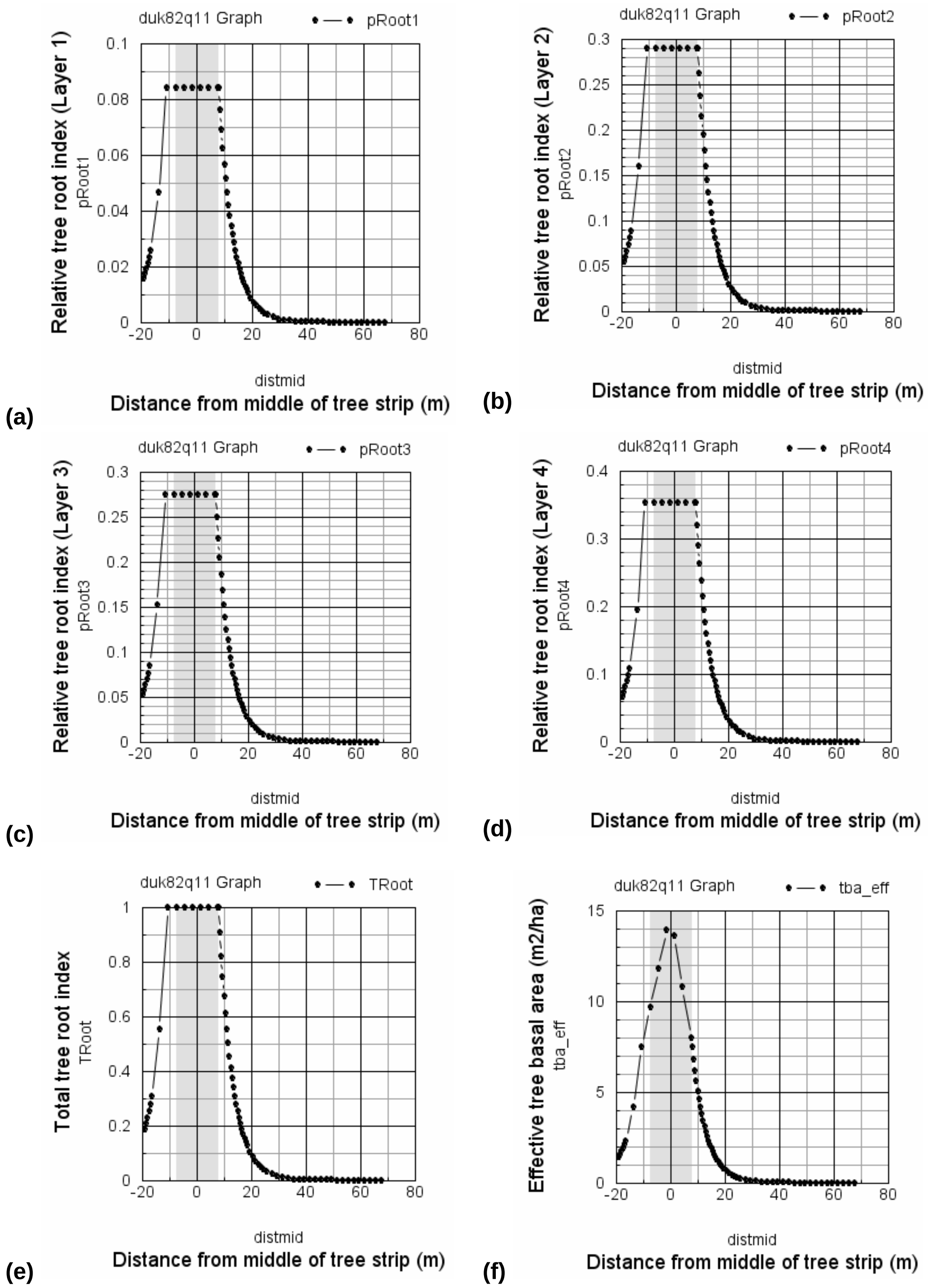
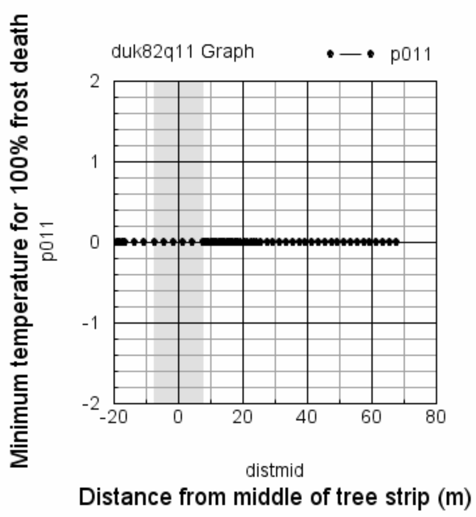
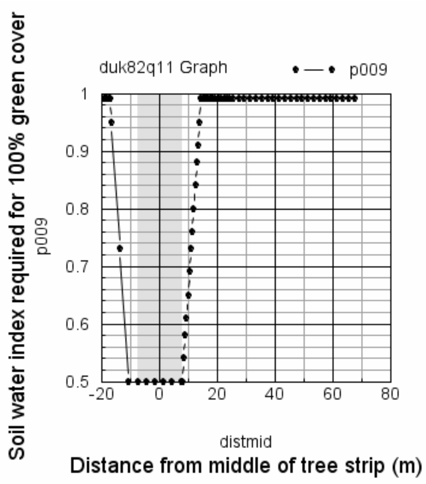


Figure 4.6.4. Relationship between distance from the middle of the tree strip and model parameters describing tree root effects along the transect: (a) relative tree root index for soil layer 1 (0-10cm); (b) relative tree root index for soil layer 2 (10-50cm); (c) relative tree root index for soil layer 3 (50-100cm); (d) relative tree root index for soil layer 4 (100-200cm); (e) total tree root index calculated as the addition of the four soil layers; and (f) effective tree basal area combining tree basal area and root indices.



(a)



(b)

Figure 4.6.5. Relationship between distance from the middle of the tree strip and model parameters along the transect: (a) minimum temperature for 100% death due to frost; and (b) soil water index required to support 100% green cover.

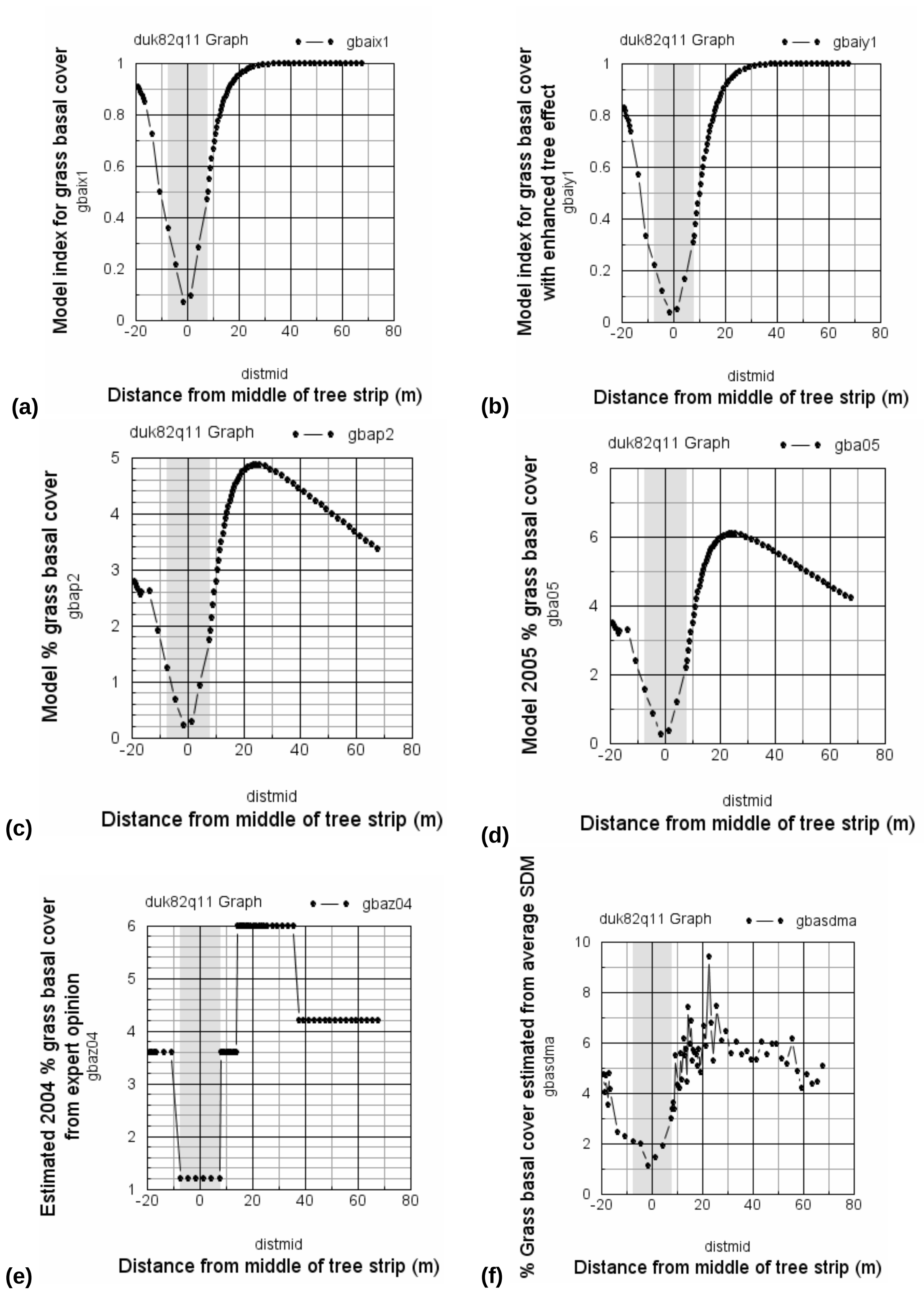


Figure 4.6.6. Relationship between distance from the middle of the tree strip and model indices of grass basal cover: (a) index of grass basal cover calculated from effective tree basal area; (b) index of grass basal with enhanced tree competition effect; (c) modelled percent grass basal cover; (d) modelled grass basal cover in 2005; (e) estimated grass basal cover in 2004 from expert opinion; and (f) grass basal cover estimated from measured standing dry matter averaged at the end of the growing seasons of 2004 and 2005.

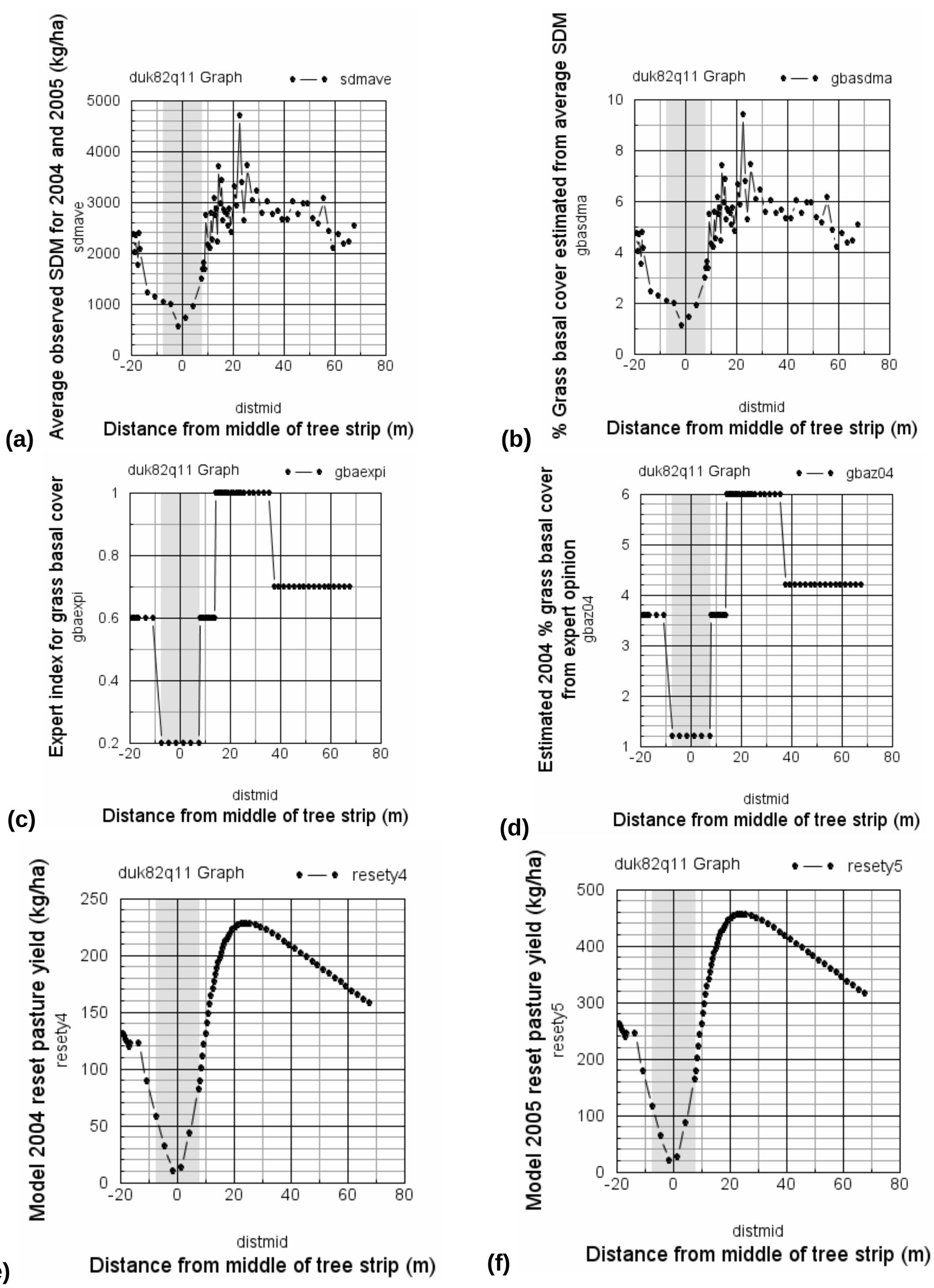


Figure 4.6.7. Relationship between distance from the middle of the tree strip and components of grass basal cover calculation: (a) average observed standing dry matter for 2004 and 2005; (b) percentage grass basal cover estimated from the average standing dry matter; (c) index of grass basal cover derived from expert opinion; (d) estimated grass basal cover in 2004 from expert opinion; (e) estimated reset yield in 2003 for the 2004 growing season; and (f) estimated reset yield in 2004 for the 2005 growing season.

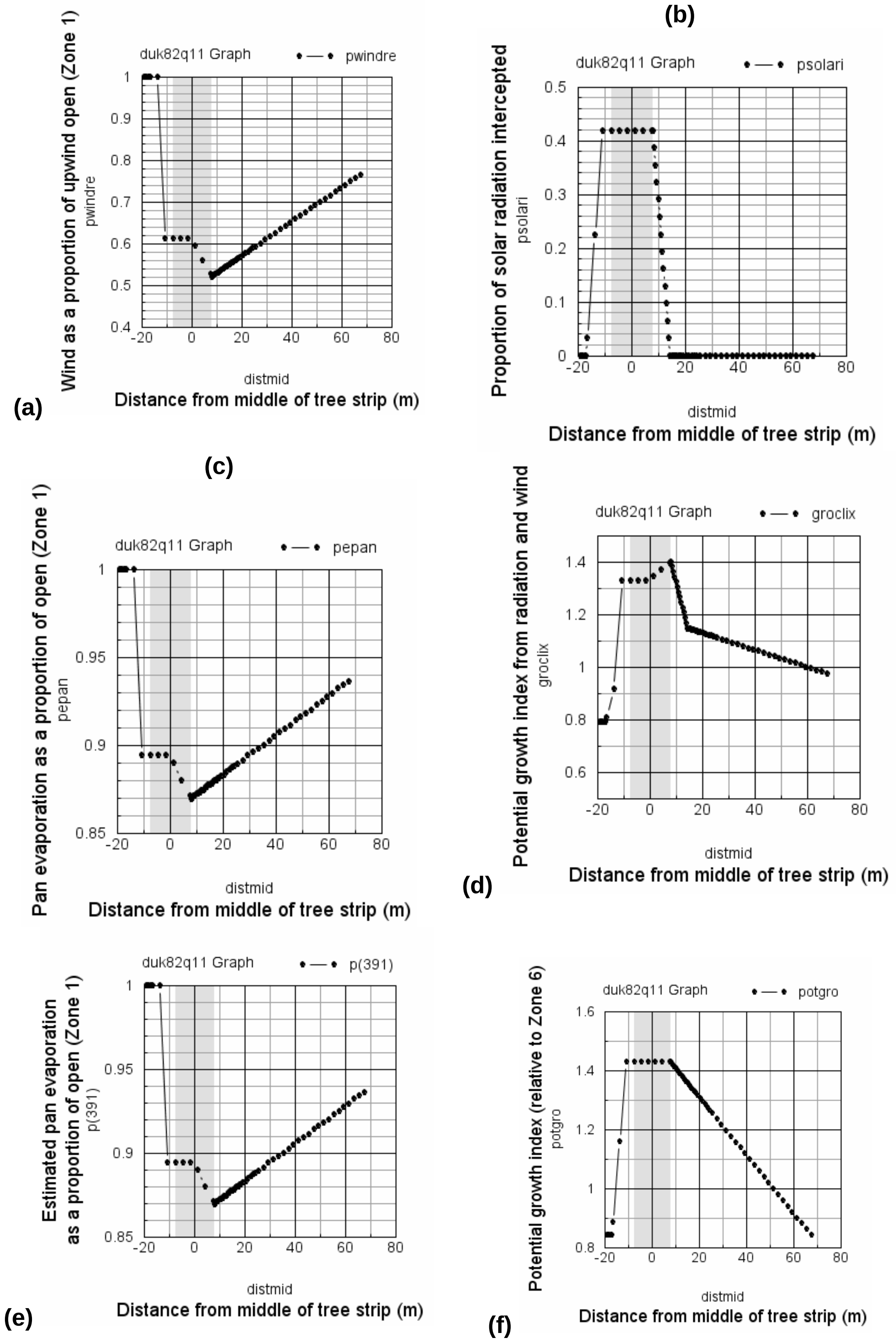


Figure 4.6.8. Relationship between distance from the middle of the tree strip and attributes of the pasture transect: (a) wind as a proportion of upwind open pasture (Zone 1); (b) solar radiation intercepted as a proportion of the open; (c) transect pan evaporation as a proportion of estimated open pasture pan evaporation; (d) a potential growth index calculated from solar radiation and wind effects; (e) model parameter for proportion of estimated pan evaporation; and (f) potential growth index relative to Zone 6 (repeated from Figure 4.6.2a).

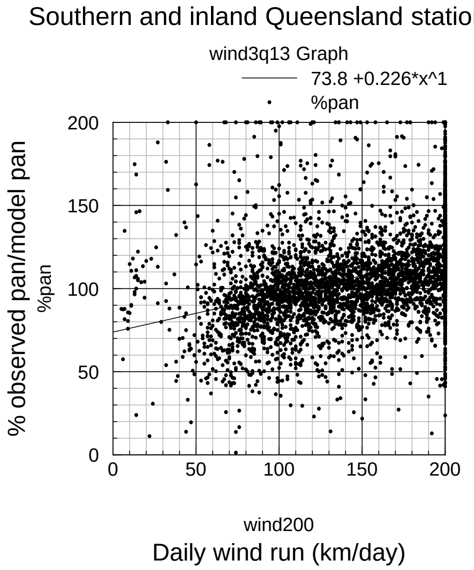


Figure 4.6.9. For six stations in southern and inland Queensland the relationship between daily wind run and the ratio of observed Class A pan evaporation to 'model' pan was calculated from the muilti-regression pan = -0.481 + 0.1694 vpd + 0.1637 Solar_radiation derived previously from the SILO surfaces for the same region.

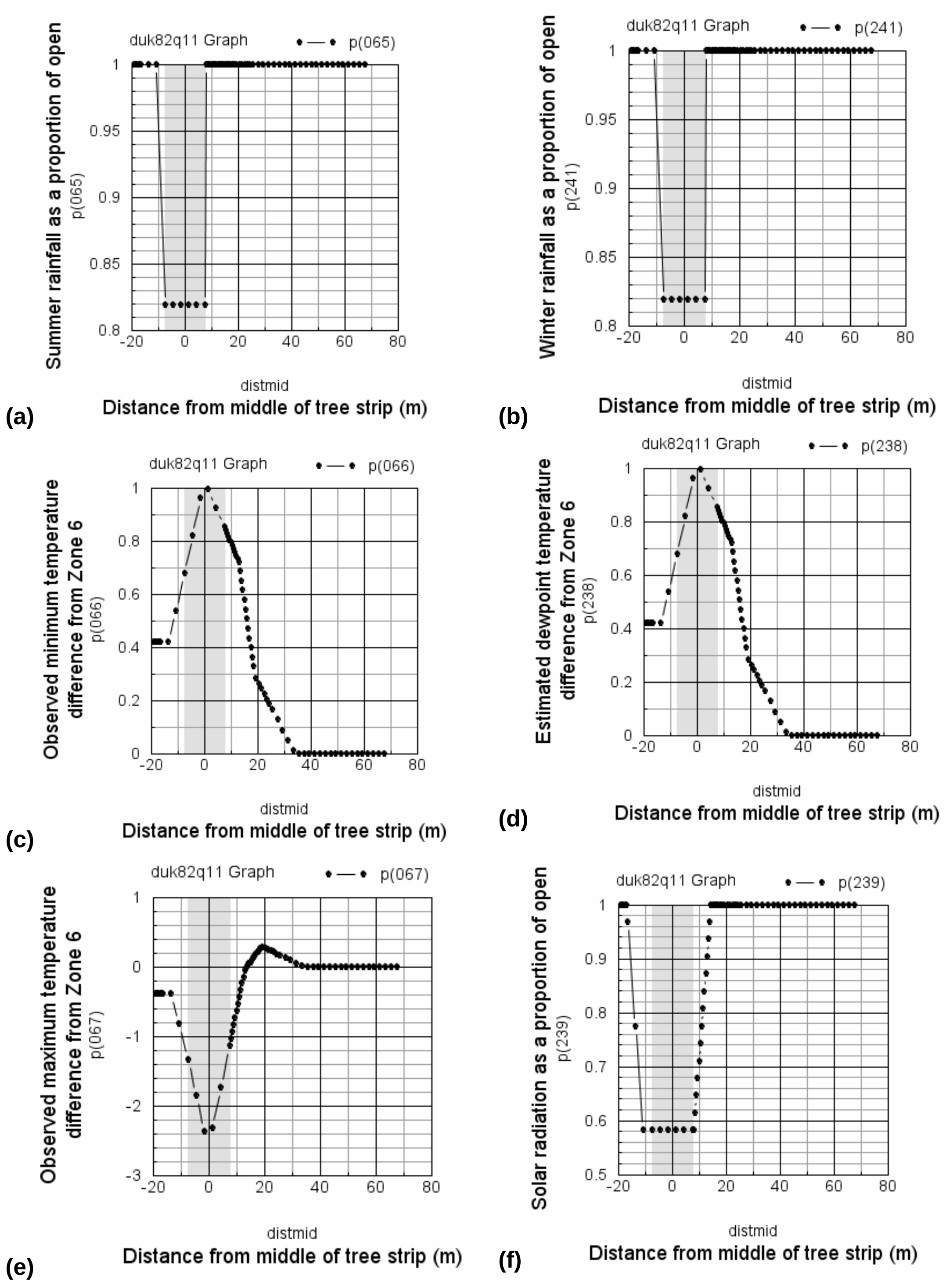


Figure 4.6.10. Relationship between distance from the middle of the tree strip and model parameters along the pasture transect: (a) summer rainfall as a proportion of open pasture; (b) winter rainfall as a proportion of open pasture; (c) minimum temperature difference from open pasture; (d) dewpoint temperature difference from open pasture; (e) maximum temperature difference from open pasture; and (f) solar radiation as a proportion of open pasture.

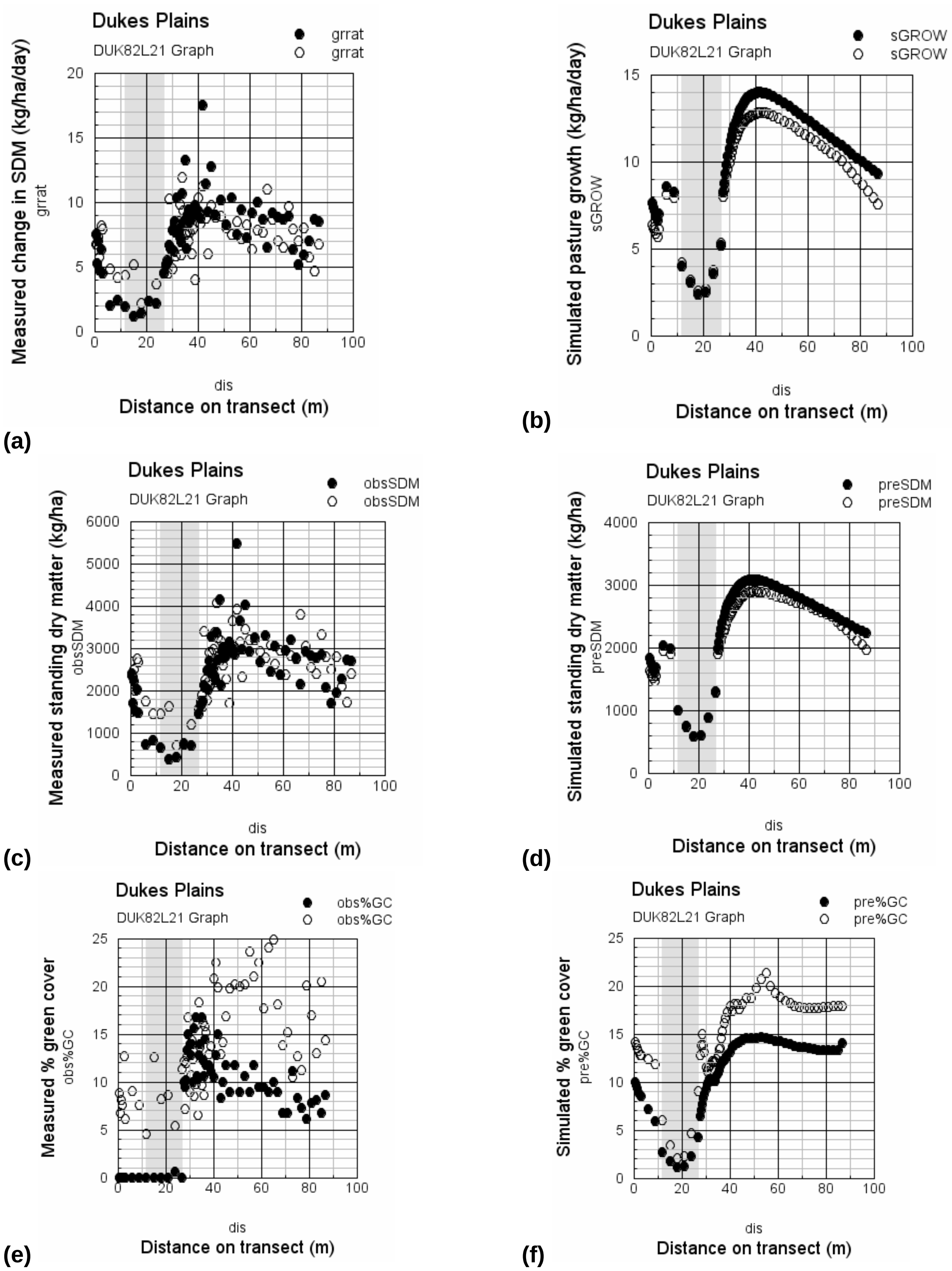


Figure 4.6.11. For each season (● 2004, ○ 2005), measured or simulated pasture components along the pasture transect (0 metres at start of Zone 1): (a) measured change in pasture standing dry matter; (b) simulated seasonal pasture growth; (c) measured standing dry matter in May; (d) simulated standing dry matter in May; (e) measured green cover in May; and (f) simulated green cover in May.

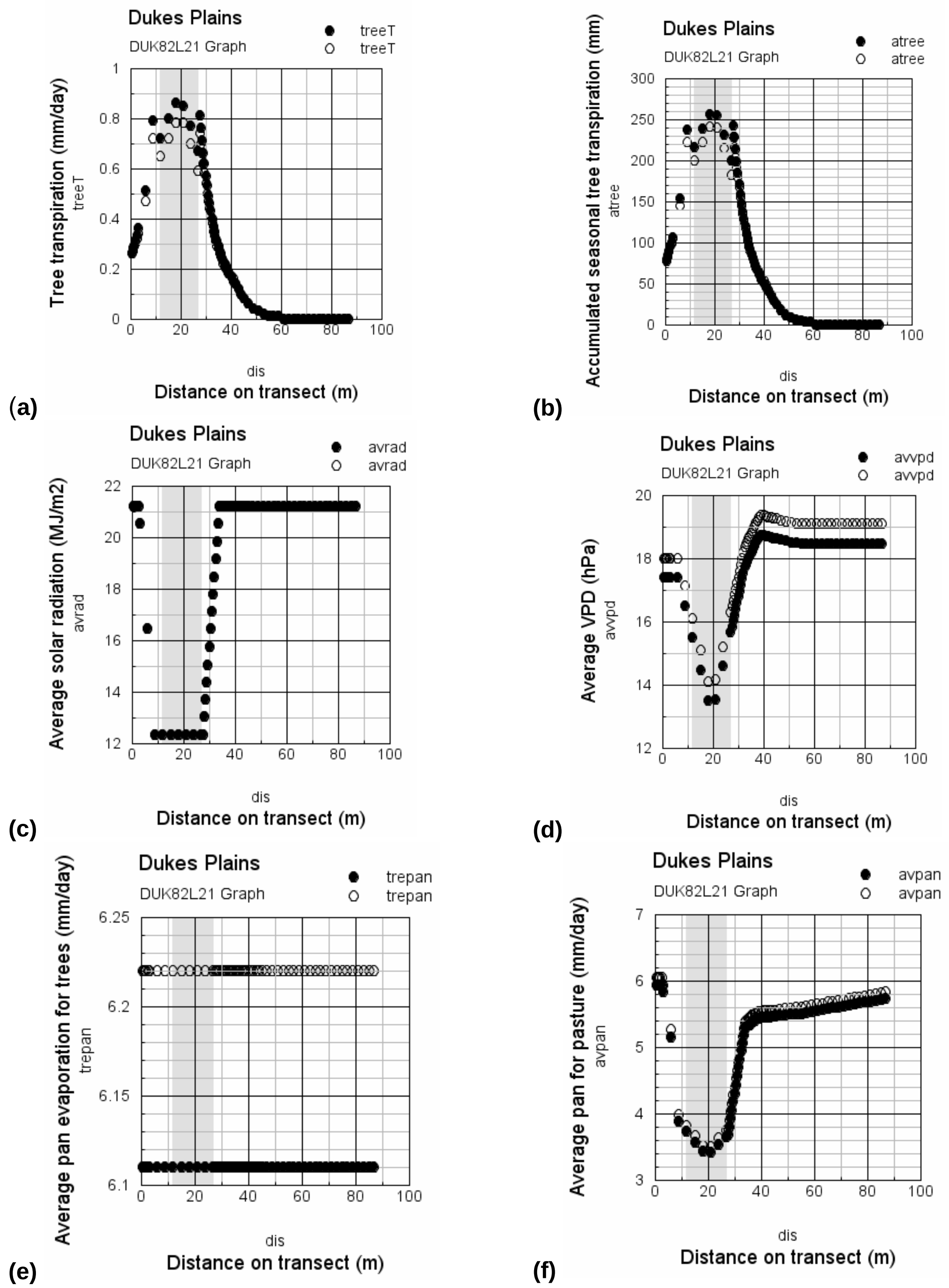


Figure 4.6.12. For each season (● 2004, ○ 2005), tree and climate components along the pasture transect (0 metres at start of Zone 1): (a) simulated seasonal tree transpiration (mm/day); (b) simulated accumulated seasonal tree transpiration (mm); (c) average seasonal solar radiation; (d) average seasonal vapour pressure deficit (vpd); (e) average seasonal pan evaporation for tree layer; and (f) average seasonal pan evaporation for pasture layer.

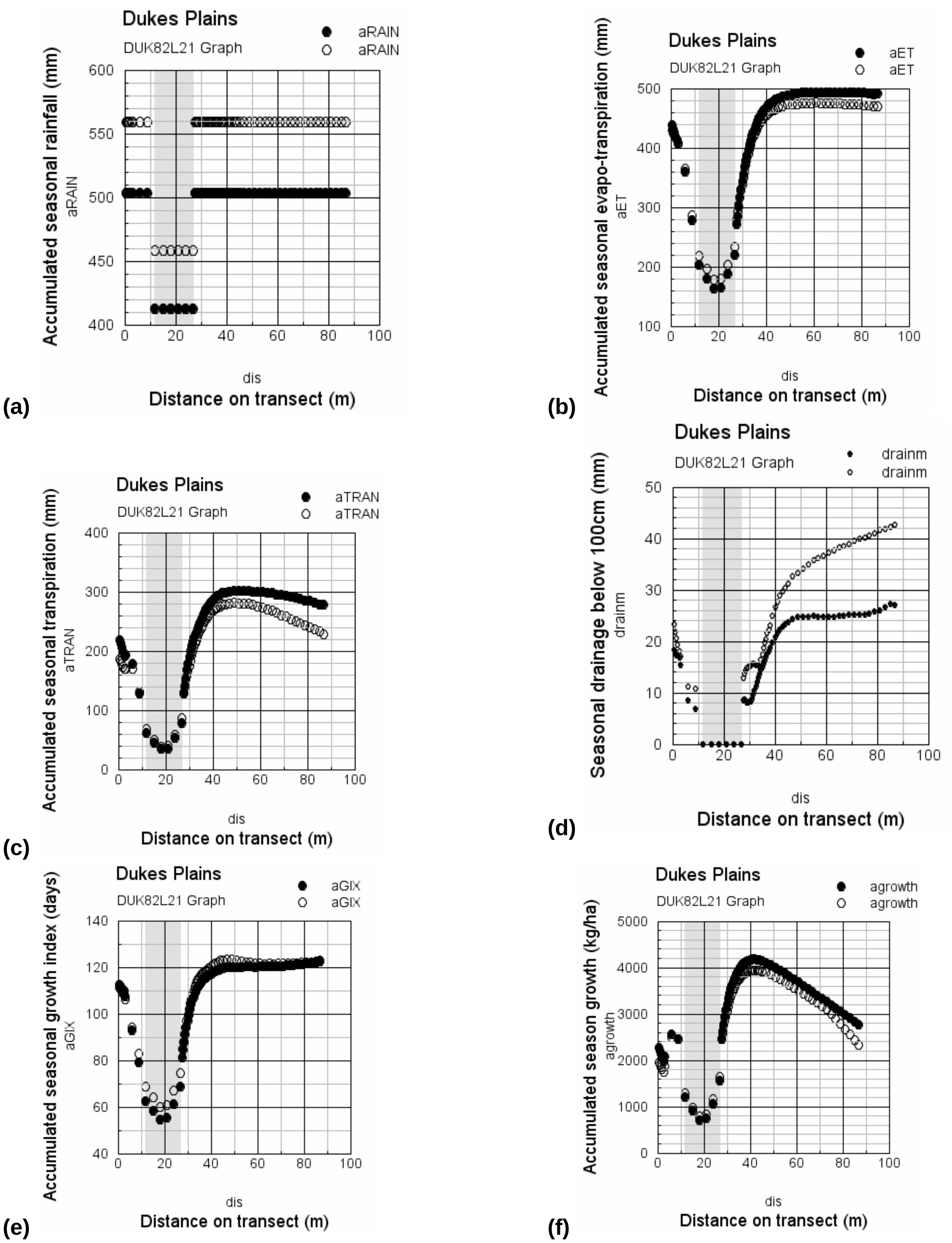


Figure 4.6.13. For each season (● 2004, ○ 2005), accumulated indices and water balance components along the pasture transect (0 metres at start of Zone 1): (a) seasonal rainfall; (b) seasonal evapo-transpiration; (c) seasonal transpiration; (d) seasonal drainage below 100cm; (e) seasonal accumulated growth index; and (f) seasonal simulated growth.

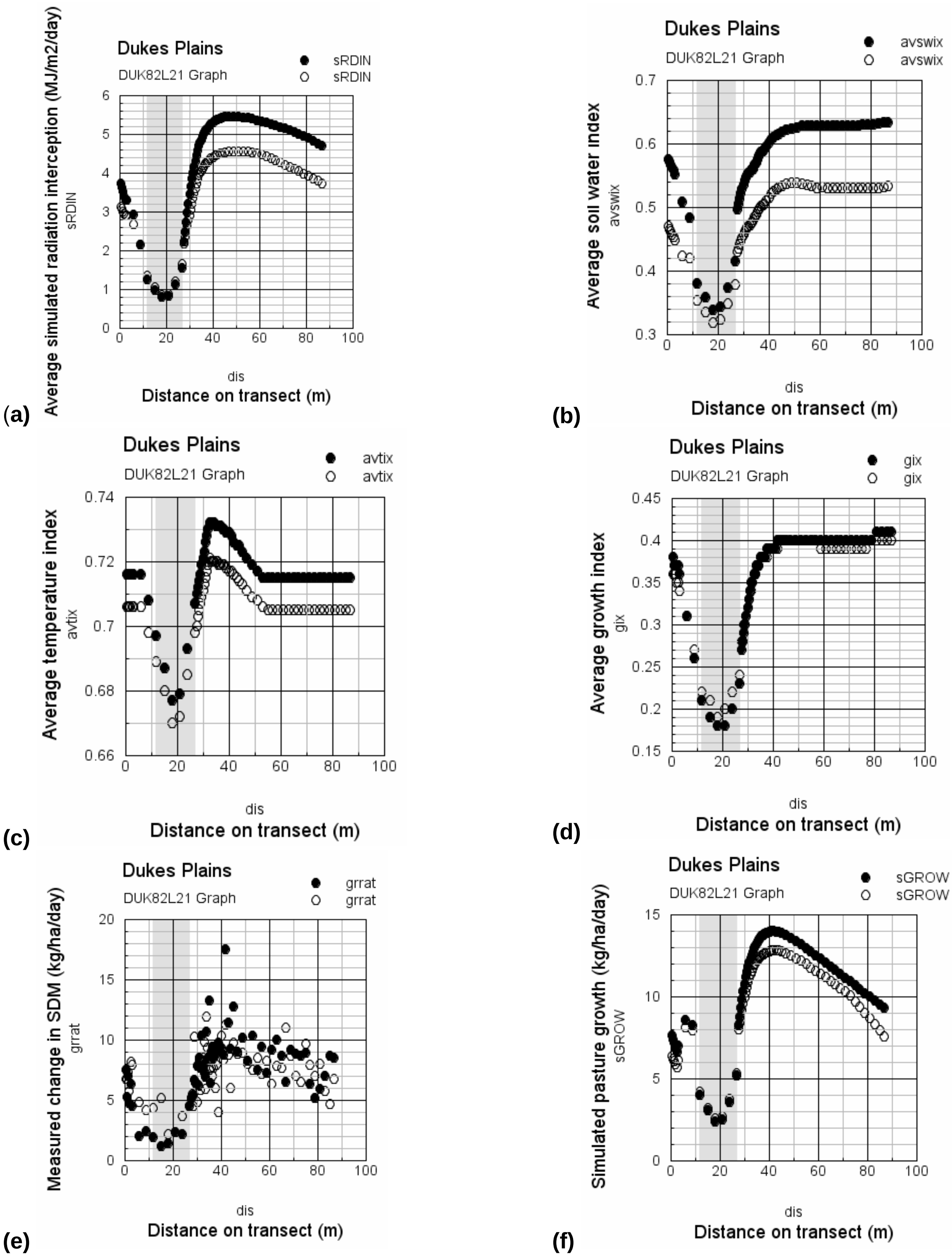


Figure 4.6.14. For each season (● 2004, ○ 2005), simulated pasture growth indices along the pasture transect (0 metres at start of Zone 1): (a) average simulated radiation interception; (b) average soil water index; (c) average temperature index; (d) average growth index; (e) measured pasture growth rate (repeat of Figure 4.6.11a); and (f) simulated pasture growth rate (repeat of Figure 4.6.11b).

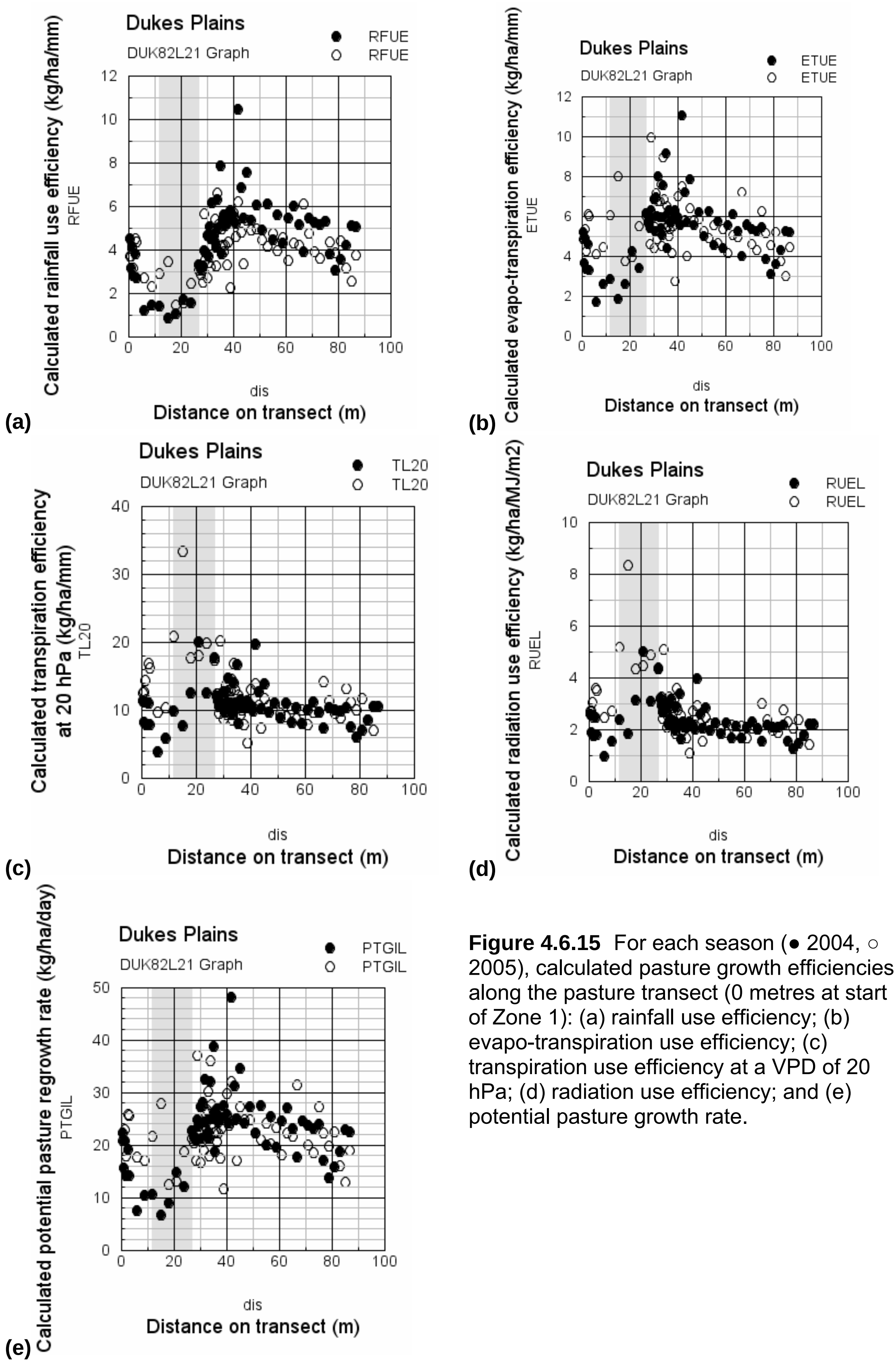


Figure 4.6.15 For each season (● 2004, ○ 2005), calculated pasture growth efficiencies along the pasture transect (0 metres at start of Zone 1): (a) rainfall use efficiency; (b) evapo-transpiration use efficiency; (c) transpiration use efficiency at a VPD of 20 hPa; (d) radiation use efficiency; and (e) potential pasture growth rate.

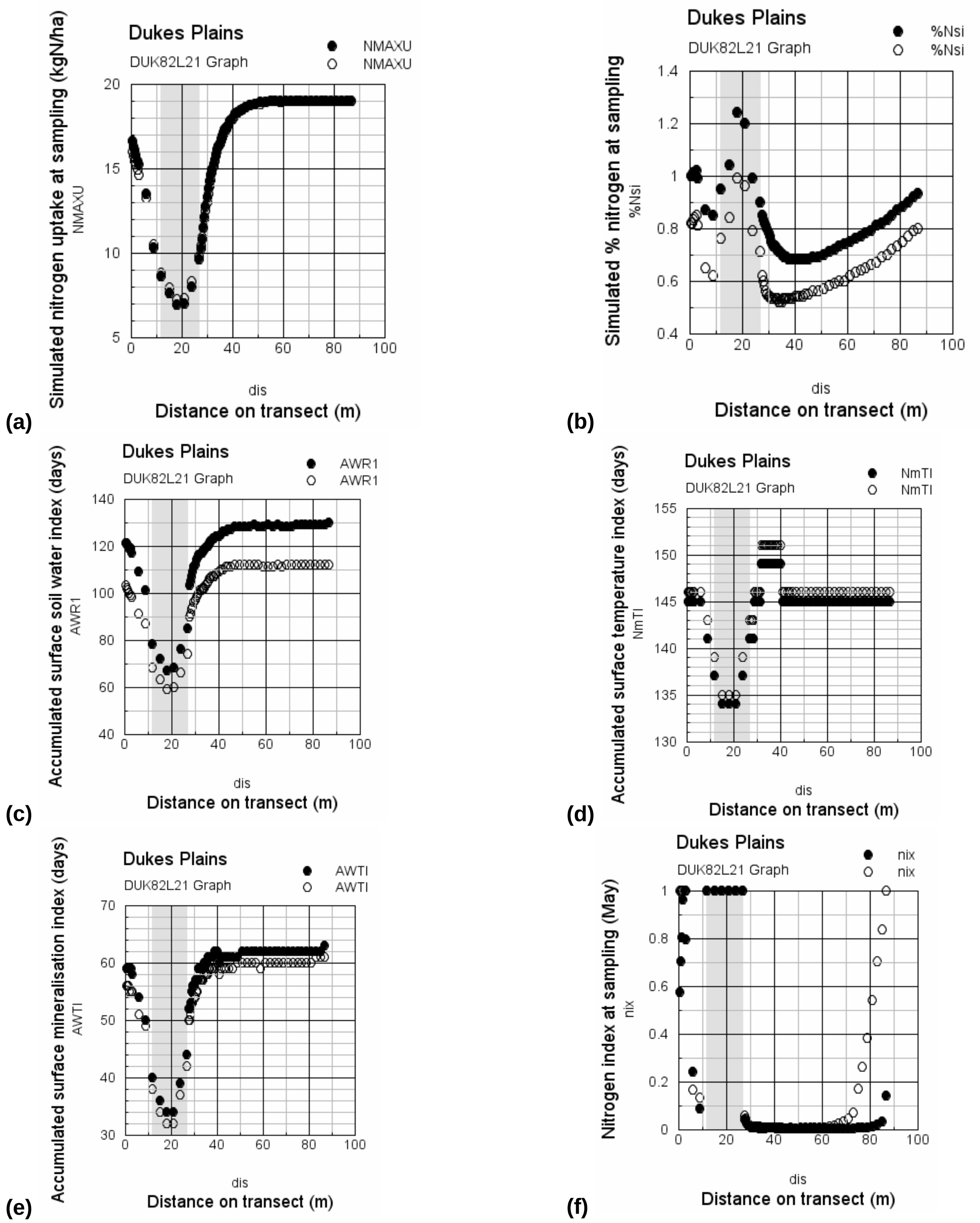


Figure 4.6.16. For each season (● 2004, ○ 2005), nitrogen uptake and concentration components along the pasture transect (0 metres at start of Zone 1): (a) simulated nitrogen pasture uptake in May; (b) simulated % nitrogen in May; (c) accumulated surface soil water index; (d) accumulated surface temperature index; (e) accumulated surface mineralisation index; and (f) nitrogen index for pasture growth (1 means no nitrogen limitation, 0 means nitrogen concentration has declined to minimum %N).

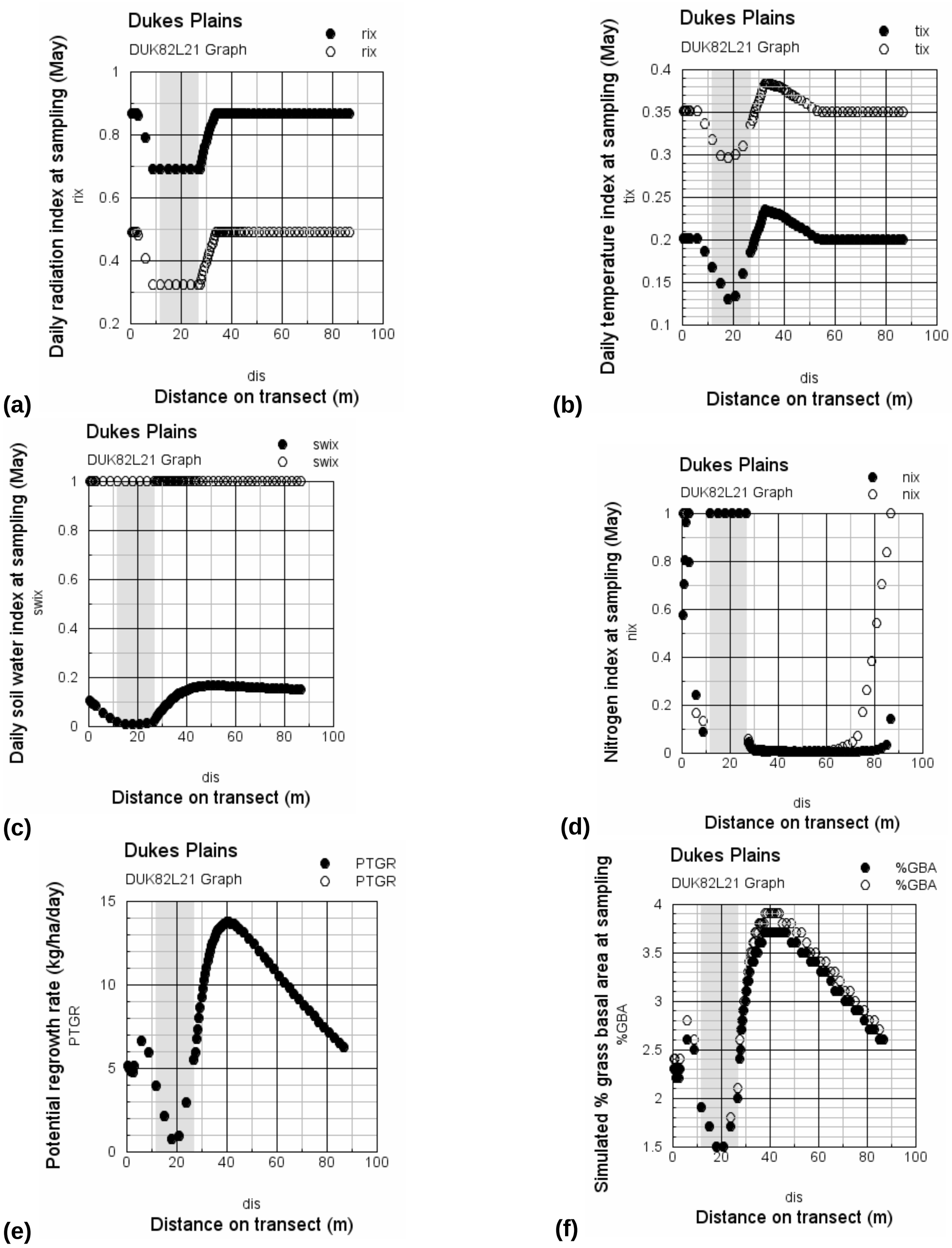


Figure 4.6.17. For each season (● 2004, ○ 2005), pasture growth indices at the time of sampling along the pasture transect (0 metres at start of Zone 1): (a) radiation index; (b) temperature index; (c) soil water index; (d) nitrogen index (repeated); (e) potential regrowth rate; and (f) simulated grass basal cover (area).

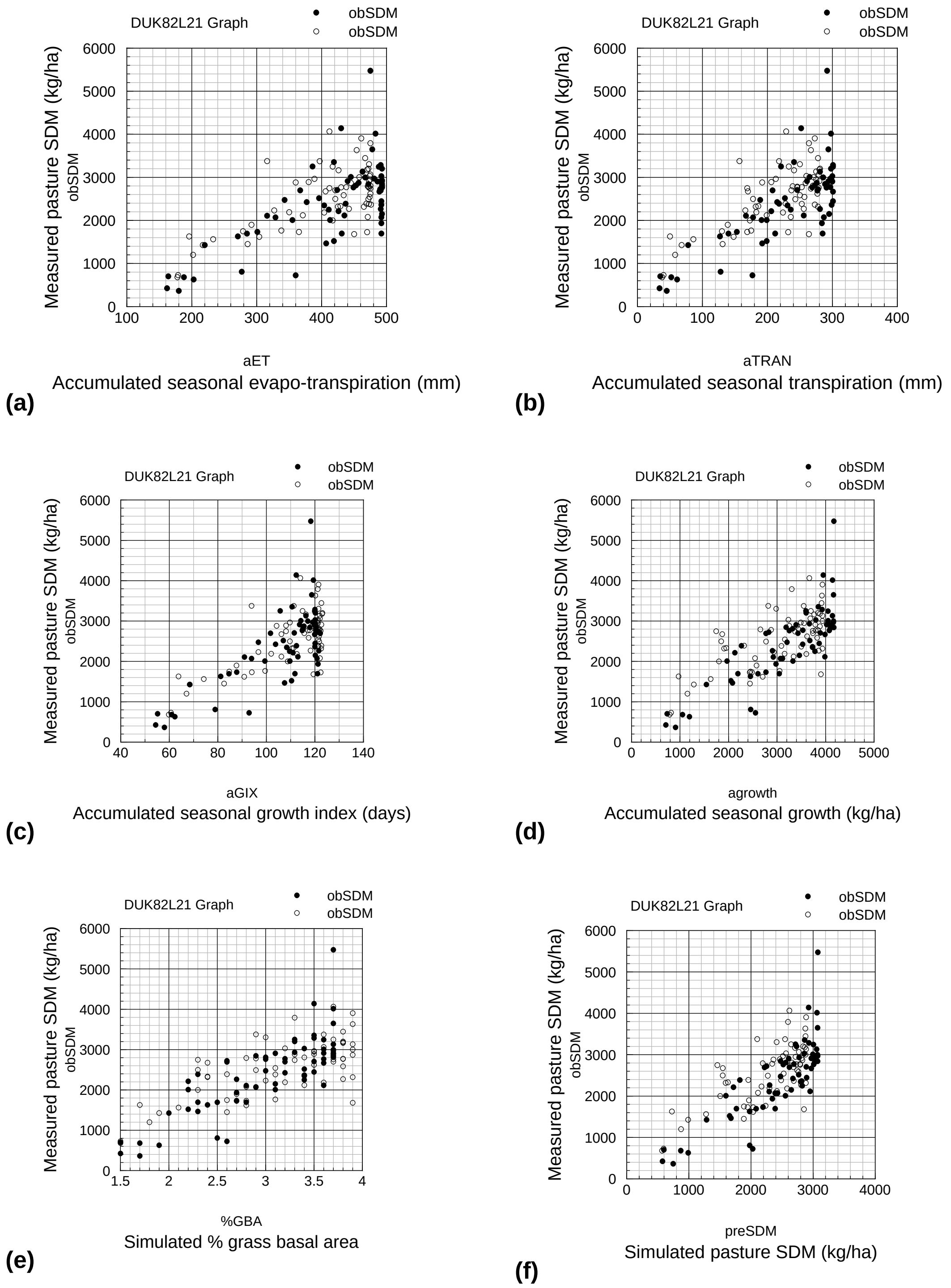
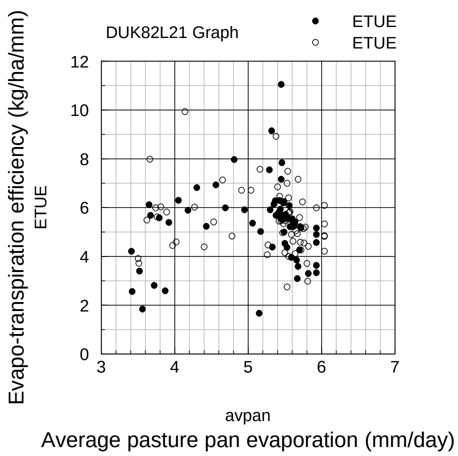
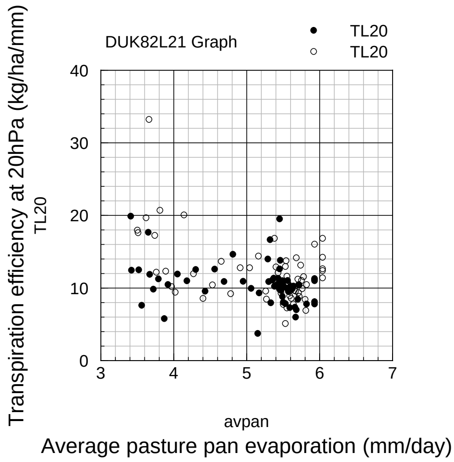


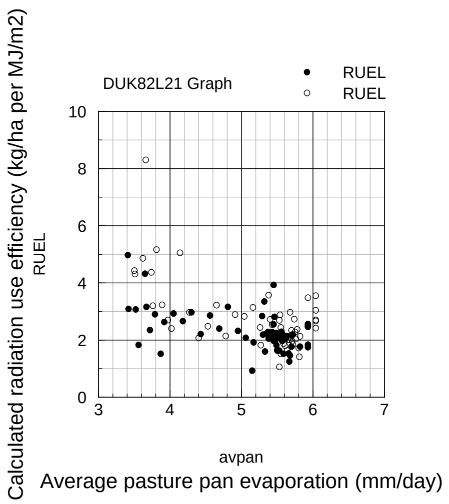
Figure 4.6.18. For each season (● 2004, ○ 2005), the relationship between measured pasture standing dry matter, and simulated water balance and growth indices along the pasture transect (0 metres at start of Zone 1): (a) accumulated seasonal evapo-transpiration; (b) accumulated seasonal transpiration; (c) accumulated seasonal growth index; (d) accumulated simulated pasture growth; (e) simulated percentage grass basal cover (area); and (f) simulated pasture standing dry matter.



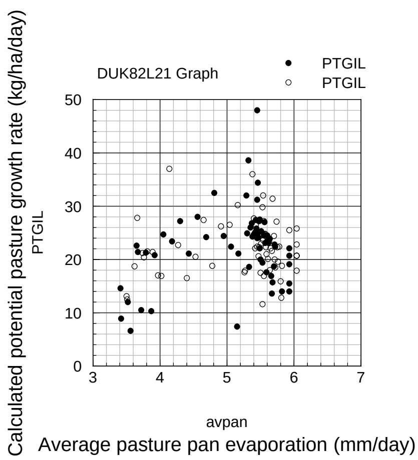
(a)



(b)



(c)



(d)

Figure 4.6.19. For each season (● 2004, ○ 2005), the relationship between average pasture pan evaporation and calculated pasture use efficiencies along the pasture transect (0 metres at start of Zone 1): (a) evapo-transpiration use efficiency; (b) transpiration use efficiency corrected to a VPD of 20 hPa; (c) radiation use efficiency; and (d) potential pasture growth rate.

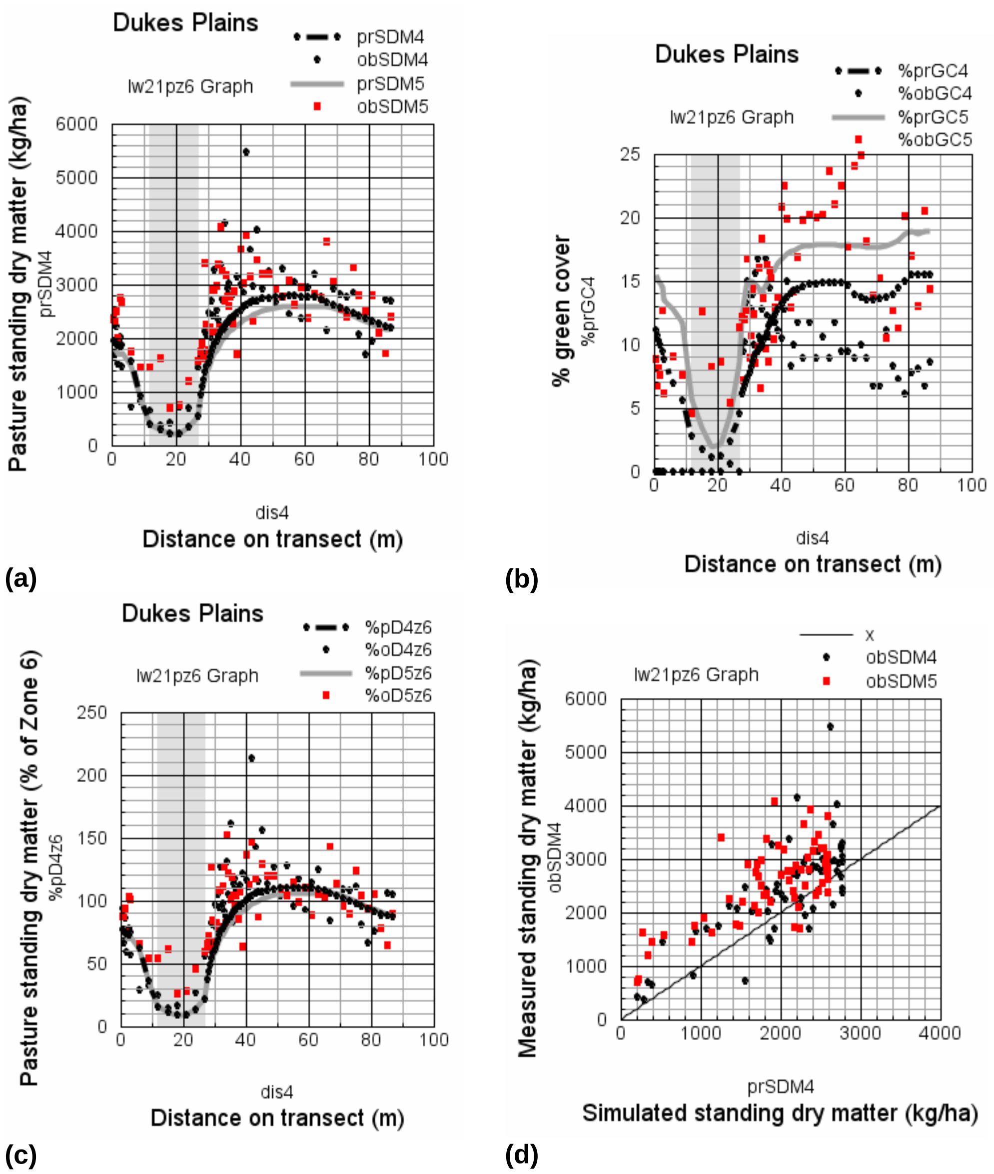


Figure 4.6.20. For average fertility parameter set at Duke's Plain for each season (2004, 2005), measured and simulated pasture components along the pasture transect (0 metres at start of Zone 1): (a) pasture standing dry matter; (b) % green cover; (c) pasture standing dry matter as a percentage of Zone 6; and (d) comparison of measured and simulated pasture standing dry matter. Symbols are: simulated 2004 (solid black line); simulated 2005 (solid grey line); measured 2004 (solid black circle); and measured 2005 (solid red square).

4.6.3.2 Simulation results for Duke's Plain in 2004 and 2005

The following section reports the results of the simulation of the Duke's Plain pasture transect using the parameterisation described above. The simulation started on 1 January 2000 with the dynamic grass basal area based on growing season evapo-transpiration. As indicated earlier no formal calibration procedure was conducted. However, site specific parameters such as maximum nitrogen uptake (19 kgN/ha) and grass basal area of open pasture were derived or estimated from transect measurements. Similarly the general relationships describing beneficial and competitive effects, which were developed from Duke's Plain and Mt Lonsdale pasture data in Section 4.5, were used in changing parameters along the pasture transect. Thus the following simulations cannot be regarded as independent of the observed data. Nevertheless the simulations provide an initial test of the separation of beneficial and competitive effects of the tree strip, and a logical approach to extrapolation to other year-types and locations.

Figure 4.6.11 shows measured and simulated pasture growth (Figures 4.6.11a and b), standing dry matter (Figures 4.6.11c and d) and green cover (Figures 4.6.11e and f) along the pasture transect. The overall seasonal climate and growth indices are summarised in Table 4.6.3. The season ending May 2005 was wetter than season ending May 2004 in terms of total rainfall. However, when the components of the soil water balance were considered (tree transpiration, pasture evapo-transpiration and pasture transpiration), the 2004 season had more moisture available for (tree or pasture) growth than 2005. This is reflected in the slightly higher simulated growth rates and standing dry matter. The 2004 season had on average lower vapour pressure deficit and pan evaporation. As a consequence of greater water availability and lower potential evaporative demand, the average soil water index was considerably greater for 2004 than 2005. Temperatures were marginally more suitable for pasture growth as reflected in a higher temperature index in 2004. There was no difference in average solar radiation and little difference in overall growth index. Simulated pasture growth at the end of the pasture transect, i.e. at the end of Zone 6, was 19% higher in 2004 reflecting the greater moisture availability.

Green cover at the time of sampling (May) was lower in 2004 than 2005 in both measured and simulated transects reflecting the distribution of moisture within the growing season (Figures 4.6.11c and d).

Figure 4.6.12 shows the tree and climate components along the pasture transect. Simulated tree transpiration reflects the inputs of estimated tree basal area and root distribution with tree water use near zero at 50 metres along the transect (22.5 metres from the strip edge or 3.5 x tree height, Figures 4.6.12a and b).

Climate variables such as solar radiation (Figure 4.6.12c), average vapour pressure deficit (Figure 4.6.12d), average pan evaporation for trees (Figure 4.6.12e), and average pan evaporation for pasture (Figure 4.6.12f) reflected the result of the transect parameterisation of tree effects on solar radiation interception, temperature and wind. An important feature was the increasing pan evaporation away from the middle of the tree strip with increases still continuing at the end of the pasture transect (i.e. in Zone 6). The latter pattern represents the effect of wind that was parameterised in Figure 4.6.10 from wind run measurements at Duke's Plain (Section 4.1).

Figure 4.6.13a, b, c and d indicate the components of the soil water balance relevant to plant growth along the pasture transect. The patterns indicate that along most of the pasture transect, 2004 had more water available (evapo-transpiration and transpiration) for pasture growth. However, in Zone 2 there was marginally less water in 2004. These patterns were reflected in accumulated growth indices (combining daily soil water index with temperature and radiation indices) and simulated pasture growth, including the limitations of nitrogen availability. Despite the differences in rainfall between years, simulated growth indices indicate little difference between the years along the transects which was in general agreement with pasture measurements.

GRASP calculated 'through-drainage' assuming that water flow is not restricted and hence provides an indicator of excess water in the pasture root zone. Figure 4.6.13d shows the calculated 'through-drainage' below the pasture root zone (0-100cm) along the transect. There was no through-drainage within the tree strip, but in the open pasture where tree roots were not regarded as present, simulated drainage increased to 20-40mm in each year. Calculated drainage was higher in 2005 which contributed to the lower water available for evapo-transpiration, despite the higher rainfall in this year. The other reason for lower evapo-transpiration in 2005 was that rain occurred at the end of the growing season and the simulation suggested that soil moisture was still present at the time of sampling.

Overall, Figure 4.6.14 shows the simulated growth indices that make up the pasture growth index along the transect. The 2004 season had higher indices associated with radiation interception, average soil water index and temperature index. However, the combined daily growth index averaged across the season did not show substantial differences between the years. The observed pasture growth rates estimated as the change in standing dry matter (from reset in July to harvest in May) and simulated pasture growth rates. (Figures 4.6.14e and f) show little difference between years along the pasture transect.

Figure 4.6.15 shows the calculated efficiencies of pasture growth along the transect derived from estimated pasture growth rate (Figure 4.6.14e) and components of soil water balance and growth indices. Rainfall use efficiencies (RFUE, kg/ha/mm, Figure 4.6.15a) range from 1-8 with open pasture ranging from 2.5-5. The ranges reflect the individual quadrat variability. Evapo-transpiration use efficiencies (ETUE, kg/ha/mm, Figure 4.6.15b) range from 2 kg/ha/mm in Zone 2 to 6-8 at 40 metres (approximately 2 x tree height from the strip edge). Rainfall use efficiencies and evapo-transpiration use efficiencies show a decline from 2 x tree height to the end of Zone 6 (8 x tree height).

Transpiration use efficiency was calculated from simulated transpiration when soil moisture was not limiting plant growth. Transpiration use efficiency (TUE, kg/ha/mm, Figure 4.6.15c) was then corrected for seasonal vapour pressure deficit (VPD, hPa) to a standard VPD of 20 hPa. The calculated TUE showed less variation than the RFUE and ETUE with only a small trend from the edge of the tree strip to the end of Zone 6.

Radiation use efficiency (RUE, kg/ha per MJ/m^2, Figure 4.6.15d) shows relatively constant values from 40-80 metres (2 - 8 x tree height), but was higher within the vicinity of the tree strip and the shaded zone (27.5-40 metres from the edge of the tree strip to 2 x tree height). Figure 4.6.15e shows the potential growth rate calculated by dividing estimated pasture growth by the average seasonal growth index. Potential pasture regrowth rate follows a similar pattern to RFUE and ETUE.

The overall conclusion from comparison of the various efficiencies is that corrected transpiration use efficiency was close to constant, except for the immediate vicinity of the tree strip whilst RUE had a strong core linear relationship away from the tree strip. A later section examines the possible link between these efficiencies and other transect attributes such as pan evaporation.

The analysis presented in Figure 4.6.15 provided an opportunity to independently assess the beneficial effects of tree strips on derived variables such as transpiration use efficiency (TUE) and radiation use efficiency (RUE). The TUE and RUE values were derived from measurements of pasture standing dry matter and simulated transpiration and solar radiation interception respectively. As a consequence, the derived TUE and RUE include the effects of variable detachment rate and nitrogen limitations, and the derived TUE and RUE are thus not likely to fully represent the effect of tree strip on these parameters. Nevertheless, TUE and RUE at the edge of the tree strip (≈30m on transect) range from 0-50% above values towards the end of transect (Zone 6, 57-87m on transect). Thus the hypothesised beneficial effect of ≈40% (a_1 = 1.42 in Equation 4, Section 4.5) was not incompatible with these derived values. However, derived values within the tree strip (12 to 27m on transect) were 2 to 2.5 times Zone 6 values suggesting that estimation of these growth parameters (TUE, RUE) in the transect model could be improved.

Figures 4.6.16a and b show nitrogen uptake (kg N/ha) and simulated nitrogen concentration at the time of sampling respectively. For most of the pasture transect, nitrogen uptake was at the maximum possible nitrogen availability of 19kg N/ha as specified by input parameter p099. The simulated nitrogen concentration reflected: 1) the dilution of a constant N uptake based on simulated growth; 2) a variable capability to dilute nitrogen (parameter p101, Figures 4.6.3e and f); and 3) the time since peak nitrogen uptake occurred allowing %N to decline. The simulated nitrogen index at the time of sampling (Figure 4.6.16f) indicates that nitrogen was limiting across most of the transect in 2004, whilst much of Zone 6 had not reached nitrogen limitation in 2005.

Figures 4.6.16c, d and e show components of a nitrogen mineralisation index made up of surface soil water (Figure 4.6.16c) and surface temperature (Figure 4.6.16d). Although not used in the GRASP model to simulate nitrogen availability, the surface mineralisation index provides an indicator of likely climatic and tree strip effects on mineralisation. The simulated indices are similar for both years and reflected the lower soil moistures associated with the tree strip.

Figure 4.6.17 shows a snapshot of the climate and nitrogen indices at the time of sampling to provide an example of the patterns of limitation resulting from climate indices and nitrogen availability. The high soil moisture index in 2005 reflects the rain that occurred just prior to sampling, whilst the low values in 2004 indicate the growing season had essentially finished. Both seasons had low temperature indices as would be expected in May. The nitrogen index values of zero indicate nitrogen availability was limiting further pasture growth over much of the pasture transect in 2004 and the major component (up to 70m) in 2005. Thus, parameterisation of tree strip effects on maximum nitrogen uptake and minimum nitrogen concentration is likely to have a major effect on simulation of pasture growth.

Figures 4.6.17e and f show the pattern of calculated potential regrowth rate and simulated grass basal area. Potential regrowth rate is calculated from the input parameters of initial grass basal area (%) and potential regrowth rate (kg/ha/day per unit of grass basal area). The simulation commenced in 2000 and hence the simulated grass basal area in 2004 and 2005 (Figure 4.6.17f) reflected the effects of initial estimates as well as the parameterisation of evapo-transpiration use efficiency (p288, Figure 4.6.3d) used in the dynamic grass basal area model. Figure 4.6.17f indicates that the initial pattern of grass basal area along the transect was maintained through several years of simulation, suggesting that longer simulation periods could be attempted (10-100 years).

Figure 4.6.18 and Table 4.6.4 compare measured pasture standing dry matter with various simulated indices. Accumulated pasture evapo-transpiration accounted for 48% of the combined 2004 and 2005 SDM data. Similarly, estimated transpiration accounted for 54% of combined 2004 and 2005 SDM data. Simulated growth (Figure 4.6.18d) accounted for a greater proportion of the variation (56%) in years and along the transect than the other indices indicating the importance of including nitrogen limitation in the simulation of pasture growth. Figures 4.6.18e and f compare simulated grass basal area and simulated standing dry matter with measured pasture standing dry matter respectively. The strong relationships confirm that the parameterisation described above provided a reasonable estimate of the effects of tree strip along the transect.

Figure 4.6.19 examines the relationship between various efficiencies and average pasture pan evaporation along the transect. The major impact of tree strips on climate was the effect on wind and potential evapo-transpiration calculated (i.e. pan evaporation) along the transect. The comparison of efficiencies with estimated pasture pan evaporation suggests little impact of transpiration efficiency but a larger impact on radiation use efficiency e.g. (R^2 = .36 for quadratic relationship). Transpiration efficiency had been corrected to a standard VPD which may explain the lack of relationship with pan evaporation over most of the transect. In the cases of transpiration efficiency and radiation use efficiency, higher values were found in Zone 2 (within the tree strip where pan evaporation values were lower). In subsequent work (outside this report) we will investigate physiological support for relationships indicated in Figure 4.6.19. If these relationships can be derived independently from the combination of physiological theory and microclimate models of tree strip effects, then a more independent approach to parameterisation could be adopted.

Tables 4.6.5 and 4.6.6 show that simulation explained a reasonable proportion of the observed variation in pasture SDM along the pasture transect. The agreement with green cover was not as strong although the general pattern between years and along the transect was simulated. Sensitivity studies indicated that agreement could be improved by further calibration. This procedure is likely to further indicate the nature of tree effects and will be continued once measurements of soil moisture and pasture species have been considered.

Figures 4.6.20a, b, c, d compares the simulations and observed data for pasture standing dry matter, green cover and pasture standing dry matter expressed as a percentage of Zone 6. In terms of standing dry matter there was good agreement between the simulations and measured standing dry matter (R^2 = .567), expressed in terms of kg/ha or as a percentage of Zone 6. Although minimal calibration was undertaken to achieve this result, namely the use of site specific parameters, the general shape of the relationships for beneficial and competitive effects were derived from the overall pattern of Duke's Plain and Mt Lonsdale pasture data, as described in Section 4.5. Thus, the simulations cannot be regarded as completely independent of the observed data. Nevertheless, the simulation results show that parameterisation of the effects of tree strips could be regarded as a reasonable representation of the beneficial and competitive effects of tree strips, and hence can be used to extrapolate the observed results over a greater range of time and space.

For Zones 3 to 6 of the transect, the proportion of variation accounted for by the simulations (30%) was less than the fitted empirical model for Duke's Plain and Mt Lonsdale (48%, Table 4.5.2) suggesting that calibration might improve agreement and provide further insight into tree effects. However, the variation explained in individual years, 40% for 2004 and 26% for 2005 was very similar to that explained by fitted empirical equations (42% and 26% respectively, Table 4.5.2).

Table 4.6.4. The relationship between measured standing dry matter (y) and various climate and simulated variables for combined data from 2004 and 2005 (n = 128).

Variable	Equation	R^2
Rainfall	y = -2680 + 9.85x	.221
Evapo-transpiration	y = -137 + 6.36x	.483
Transpiration	y = 583 + 8.45	.541
Growth Index	y = -1128 + 33.2	.527
Simulated Growth	y = 375 + 0.67x	.563
Simulated SDM	y = 192 + 0.97x	.567

Table 4.6.5. Analysis of observed and simulated green cover (%obGC, %prGC) and pasture standing dry matter (obSDM, prSDM). Values are also expressed as a % of Zone 6; observed and simulated green cover (%Gz6, % pGz6) and pasture standing dry matter (%oDz6, %pDz6, respectively). Simulations used parameterisation described above (DUK82.mrx). Headings are: dif:y-x – difference in mean values; RMS – root mean square; absdiff – average absolute difference; RSQ – R squared expressed as a %; Slope – slope from regression of simulated and observed; interc – intercept from regression of simulated are observed.

Xvar	Yvar	Year	no	mean x	mean y	dif:y-x	RMS	Absdiff	RSQ	slope	interc
%obGC	%prGC	2004	64	8.5	10.8	2.3	4.9	4.2	28.8	0.388	7.5
obSDM	prSDM	2004	64	2401.5	2427	25.5	542.8	388.1	66.5	0.586	1020.6
%obGC	%prGC	2005	64	13.8	14.6	0.8	4.1	3.4	43.9	0.553	6.9
obSDM	prSDM	2005	64	2525.5	2272.9	-252.6	573.9	439.2	50.9	0.615	718.7
%oGz6	%pGz6	2004	64	99.9	78.7	-21.3	55	43	28.8	0.240	54.7
%oDz6	%pDz6	2004	64	93.4	95.6	2.2	21.1	15.3	66.5	0.593	40.2
%oGz6	%pGz6	2005	64	80.2	80.4	0.2	22.9	19.2	43.9	0.526	38.2
%oDz6	%pDz6	2005	64	94.5	93.4	-1.1	19.9	15.7	50.9	0.676	29.5

Table 4.6.6. Analysis of observed and simulated green cover (obs%GC, pre GC respectively) and pasture standing dry matter (obsSDM, preSDM respectively) for Duke's Plain. Values are given for Zone and also expressed as a % of Zone 6. Simulations used parameterisation described previously (DUK82.mrx).

Zone	Year	no_obs	obs%GC	pre%GC	obsSDM	preSDM
1	2004	8	0	8.5	1602.4	1780.9
2	2004	6	0.1	2.2	704.5	844.5
3	2004	13	12.4	9.1	2246.2	2490.4
4	2004	11	12.5	11.7	2982.7	2982.8
5	2004	10	10.7	14.2	3349.2	3020.3
6	2004	16	8.5	13.7	2571.7	2538.9
1	2005	8	8.3	13.0	2218.4	1638.4
2	2005	6	8.4	4.5	1203.8	838.0
3	2005	13	11.3	12.5	2402.4	2275.7
4	2005	11	14.1	14.7	2886.0	2754.9
5	2005	10	19.0	18.8	3091.0	2850.4
6	2005	16	17.3	18.1	2673.6	2433.8
Values as a % of Zone 6						
Zone	**Year**	**no_obs**	**obs%GC**	**pre%GC**	**obsSDM**	**preSDM**
1	2004	8	0	62.0	62.3	70.1
2	2004	6	1.2	16.0	27.4	33.3
3	2004	13	146.8	66.3	87.3	98.1
4	2004	11	147.3	85.5	116.0	117.5
5	2004	10	126.0	104.0	130.2	119.0
6	2004	16	100.0	100.0	100.0	100.0
1	2005	8	48.2	71.8	83.0	67.3
2	2005	6	48.8	25.0	45.0	34.4
3	2005	13	65.7	68.7	89.9	93.5
4	2005	11	81.7	80.9	107.9	113.2
5	2005	10	110.0	103.8	115.6	117.1
6	2005	16	100.0	100.0	100.0	100.0

Table 4.6.7. Sensitivity test of parameters in the simulation of observed SDM: the effect of holding individual parameters constant at open pasture value. The average absolute difference of observed-predicted pasture standing dry matter is shown.

Biophysical Process	Parameter held constant	Average Absolute Difference (kg/ha)		Proportion of Variation Explained	
		SDM 2004	SDM 2005	SDM 2004	SDM 2005
Base run all parameters	None	388	439	.665	.509
Transpiration use efficiency	p007	400	494	.665	.556
Radiation use efficiency	p008	385	438	.670	.512
Minimum and Critical % N	p101, p102	525	634	.574	.491
ET use efficiency for GBA	p288	372	433	.683	.531
Wind effect on pan evaporation	p391	392	447	.659	.504
Maximum, minimum and dewpoint temperature	p066, p238, p067	369	460	.673	.516
Solar radiation interception	p239	401	433	.654	.488

Sensitivity study

A preliminary sensitivity study was conducted using as a base the full parameterisation described above (i.e. parameters varying along the pasture transect). In turn selected parameters were set to a constant value along the transect representing open pasture values. Table 4.6.7 shows the effect for each year (2004 and 2005) on the average absolute difference between observed and predicted SDM and proportion of variation explained (R^2). Setting the parameters representing minimum nitrogen concentration to a constant had the largest impact, followed by solar radiation interception and transpiration use efficiency. Setting other parameters to constant values had little effect e.g. the wind effect on pan evaporation. Setting to constant the growth parameter that represents the ET use efficiency for calculating grass basal area resulted in a better fit to observed SDM data. This result suggests that parameterisation improvements could be made once GBA data have been reconstructed from photos. Thus the sensitivity study emphasised the importance of parameterising nitrogen dilution, transpiration use efficiency and radiation interception in representing tree strip effects along the pasture transect.

Time series of simulated soil water, green cover, and pasture standing dry matter

The time series of components of soil water and pasture were evaluated for three positions along the pasture transect: the middle of the tree strip (21 metres referred to as Zone 2); position of peak pasture yield (40 metres referred to as Zone 4); and end of the transect (87 metres referred to as Zone 6).

Figures 4.6.21, 22, 23 and 24 show the time series of simulated soil water for four soil layers (0-10cm, 0-50cm, 50-100cm and 0-100cm). The simulations show little difference in surface moisture. However, the deeper soil layers at positions closer to the tree strip had lower soil moisture. This was particularly true of soil layer three

(50-100cm), which was substantially drier within the tree strip (Zone 2) than at the two positions along the pasture transect. Thus, one of the simulated impacts of trees was generally lower soil moisture in the 0-50cm layer, resulting in less through-drainage to layer three and below the pasture zone (0-100cm).

Figures 4.6.25, 26, 27 and 28 show the pattern of development of green material, green cover and pasture standing dry matter. The season 2004 had peak green material in February, whilst in 2005 the peak occurred in early January. In the 2005 season, there were a number of pulses of growth from January to April, in contrast to 2004 season when there was less rainfall and fewer numbers of growth pulses after the February peak. At Zone 4, the growth of green material and the associated development of green cover occurred earlier in the season. The peak in green material occurred later within the tree strip in the 2004 season. Thus the timing of peaks in greenness was affected by the competition from trees.

Figures 4.6.29 and 30 show simulated nitrogen uptake and nitrogen yield. In the 2005 season, the rate of nitrogen uptake was greater at Zone 4, than at the end of the transect (Zone 6). In both years, the simulated nitrogen yield was higher at Zone 4. The increased nitrogen yield was likely to be the result of greater pasture transpiration at Zone 4 as indicated by the increased development of green cover at this position.

Figures 4.6.31 and 32 show the time series of nitrogen concentrations calculated from either nitrogen uptake or nitrogen yield (including estimated nitrogen decline). The time series show higher % nitrogen simulated under the trees (Zone 2) whilst greater dilution occurred at the position of peak yield (Zone 4). Associated with the position of peak yield (Zone 4), simulated litter dry matter (Figure 4.6.28) and surface cover (Figure 4.6.33) were higher.

Overall the time series show that the parameterisations of each position along the transect resulted in more rapid development of green cover and standing dry matter at Zone 4 associated with greater dilution of available nitrogen. The soil moisture time series support the observations indicating greater infiltration of moisture to layer 3 in the absence of tree roots (Zone 6). It is important to note that nitrogen availability was held constant along the transect in the simulation of each position. Thus, the apparent higher values of green cover development and nitrogen uptake at Zone 4 are likely to be the result of the complex interaction of tree strip effects on climate, especially wind and calculated pan evaporation.

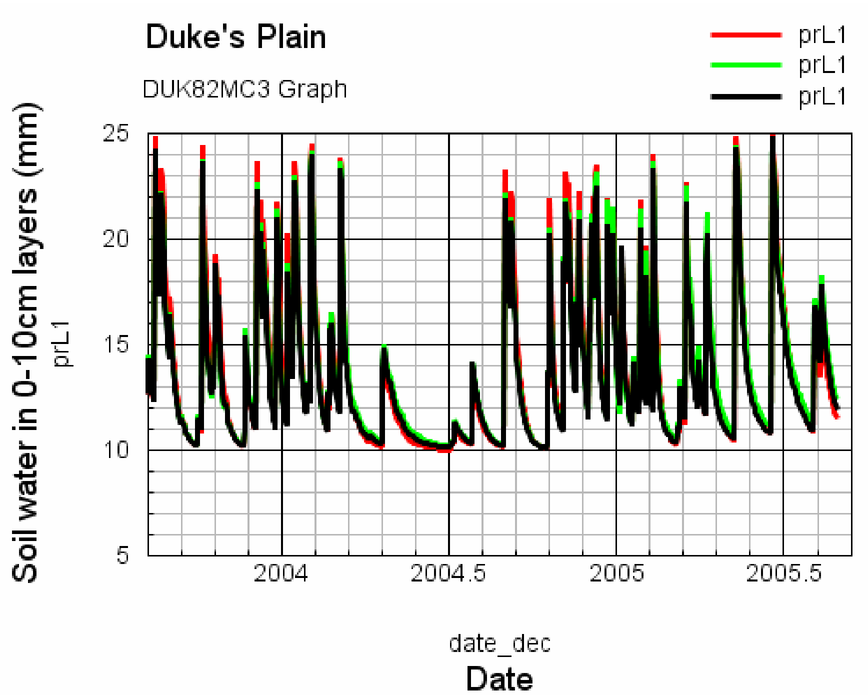


Figure 4.6.21. The time series of soil water in 0-10cm layer (mm) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

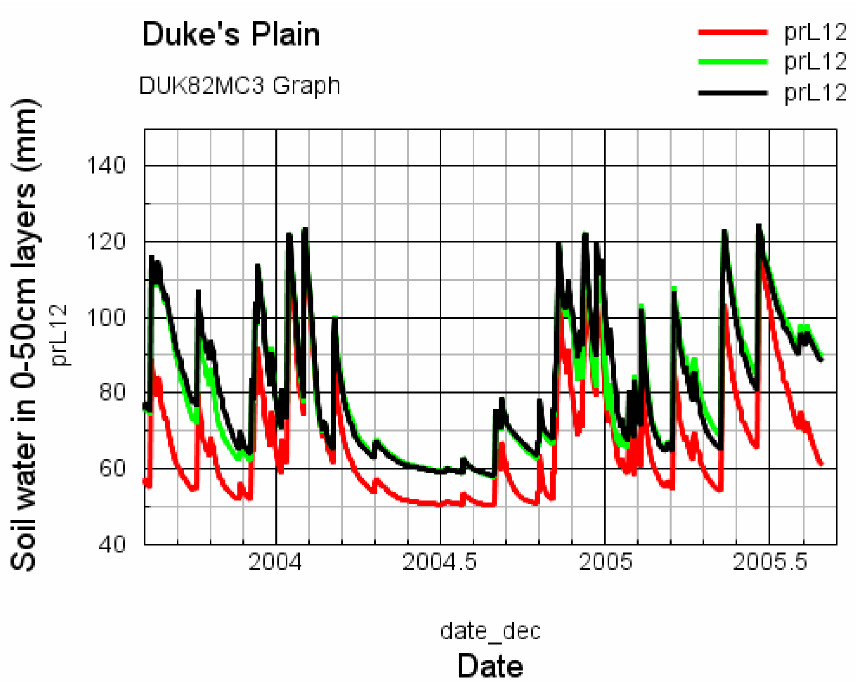


Figure 4.6.22. The time series of soil water in 0-50cm layers (mm) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

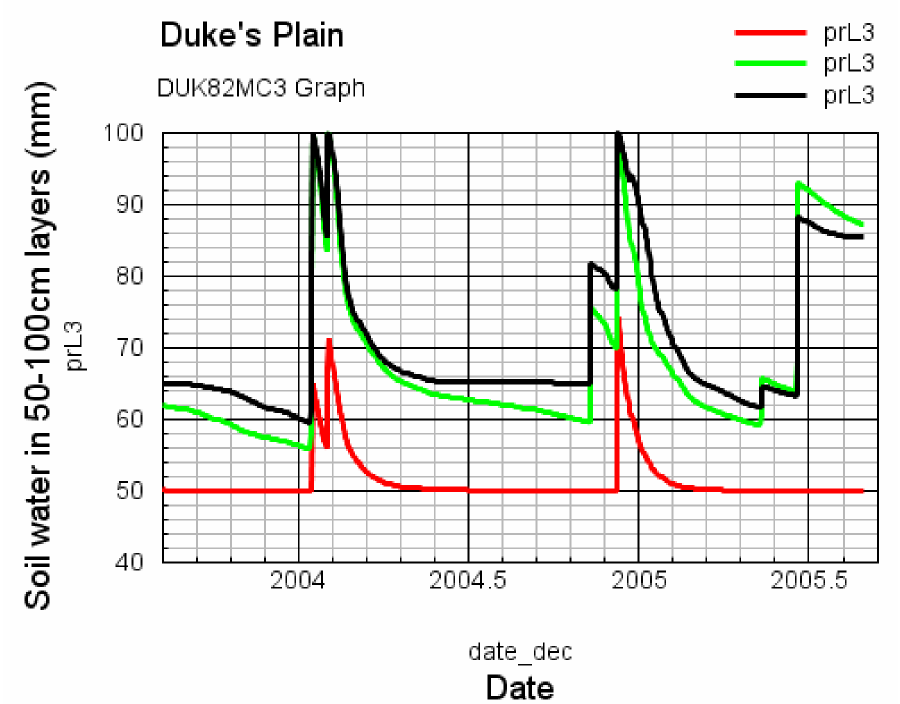


Figure 4.6.23. The time series of soil water in 50-100cm layer (mm) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

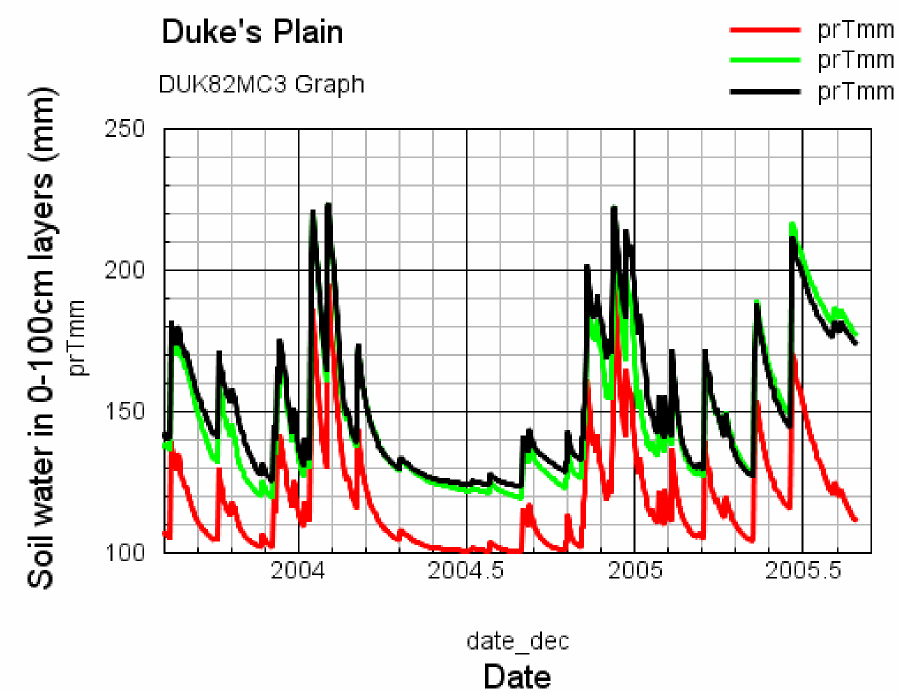


Figure 4.6.24. The time series of soil water in 0-100cm layers (mm) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

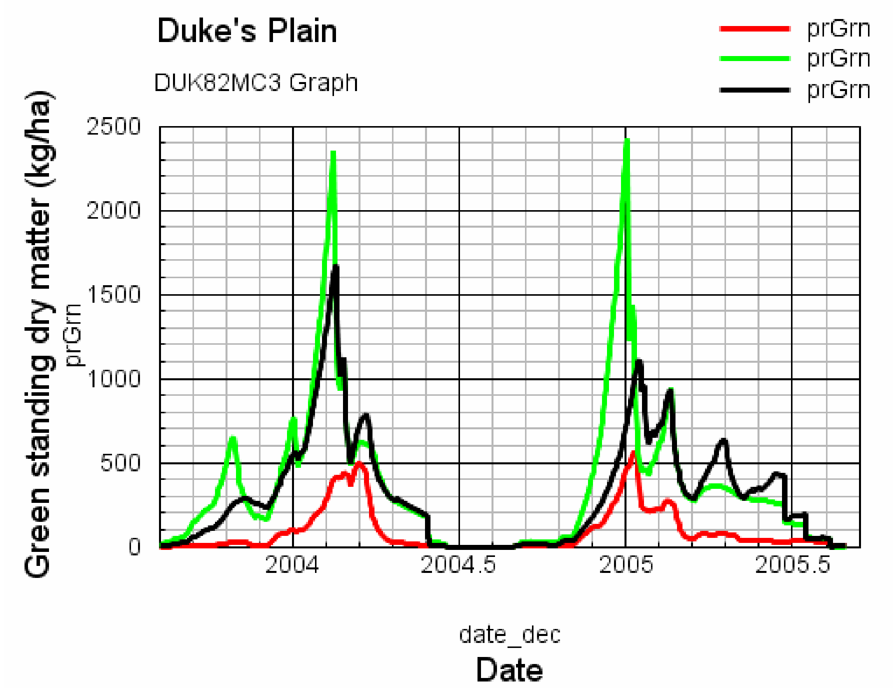


Figure 4.6.25. The time series of green standing dry matter for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

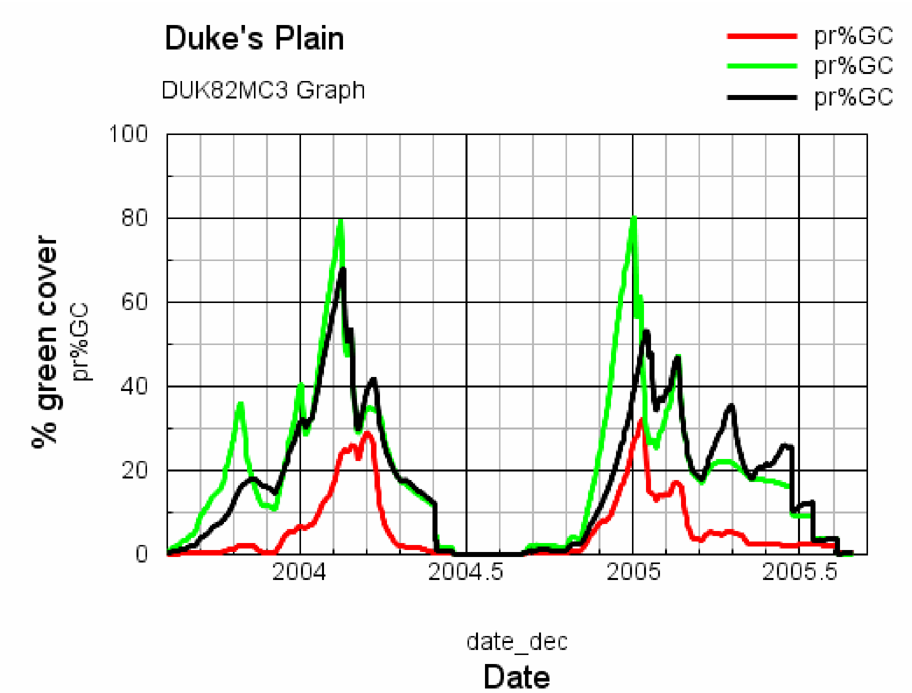


Figure 4.6.26. The time series of % green cover for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

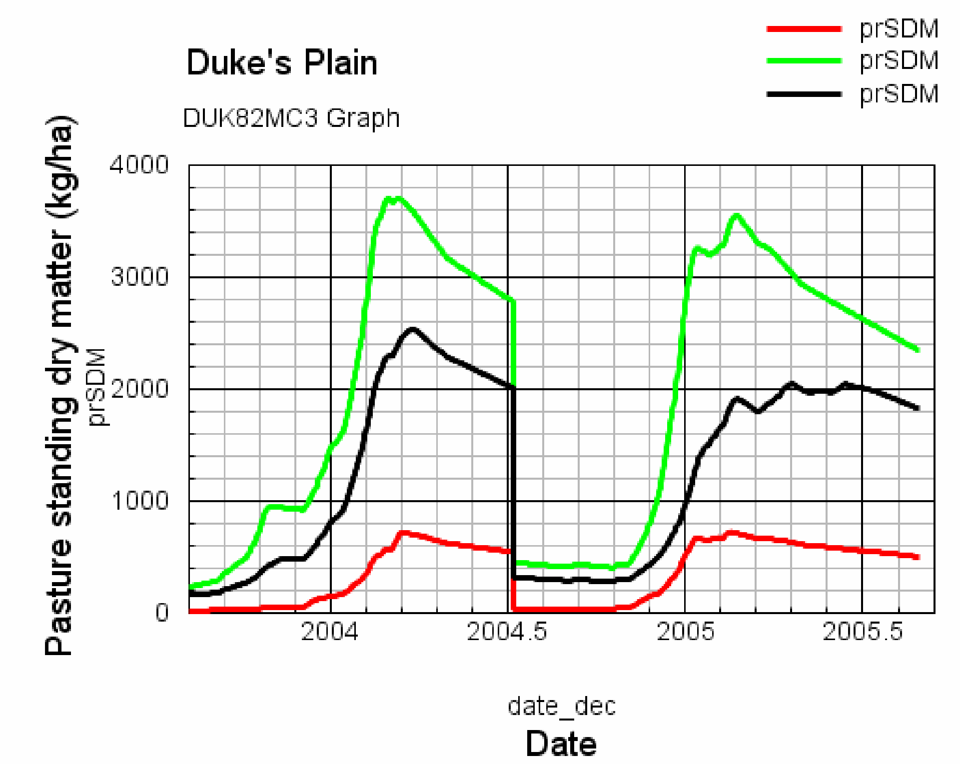


Figure 4.6.27. The time series of pasture standing dry matter (kg/ha) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

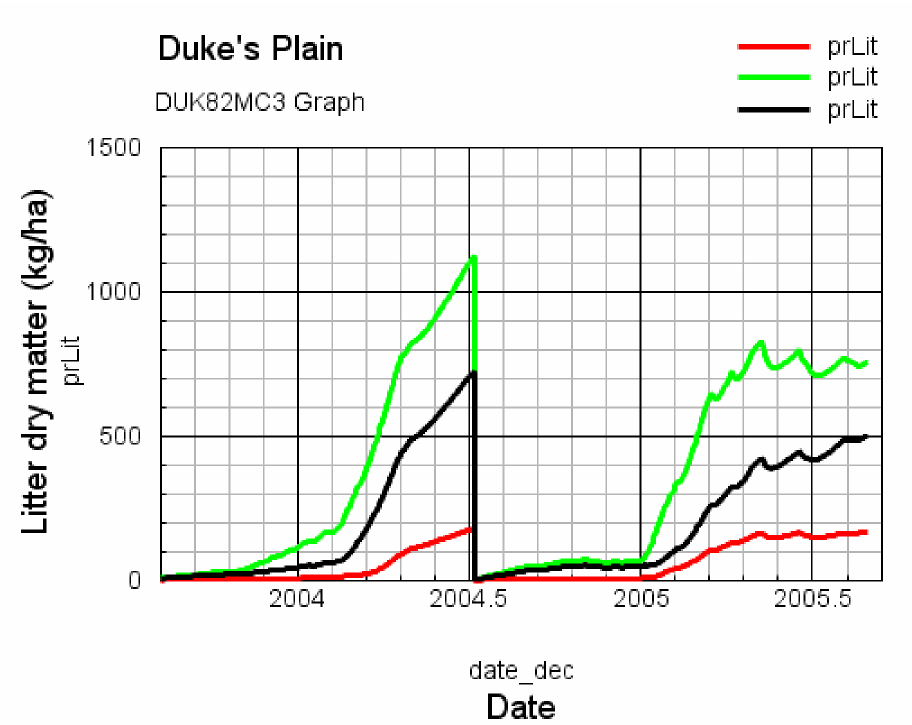


Figure 4.6.28. The time series of litter dry matter (kg/ha) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

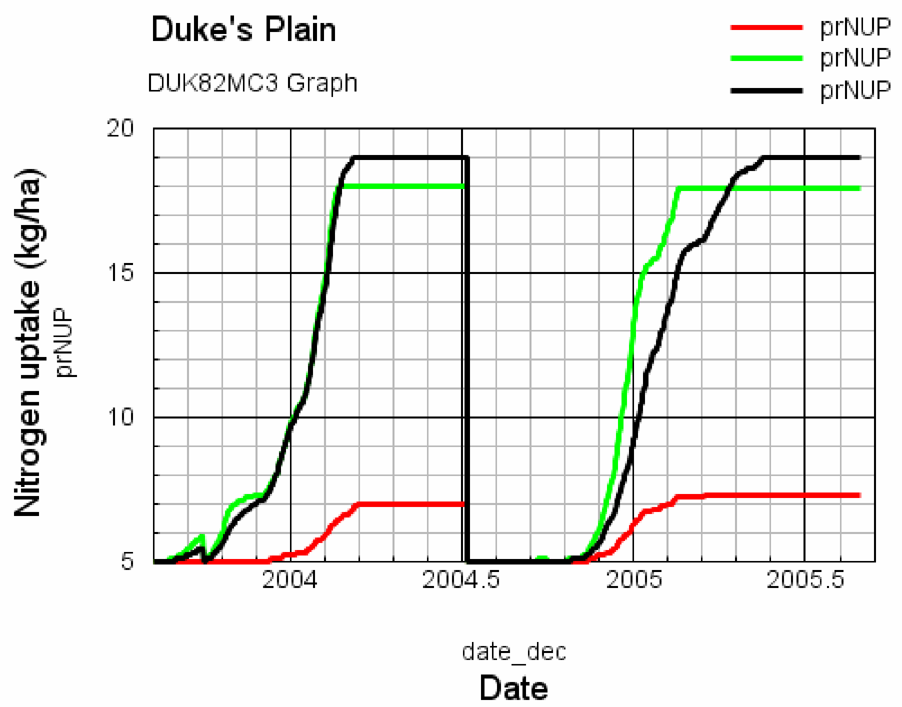


Figure 4.6.29. The time series of nitrogen uptake (kg N/ha) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

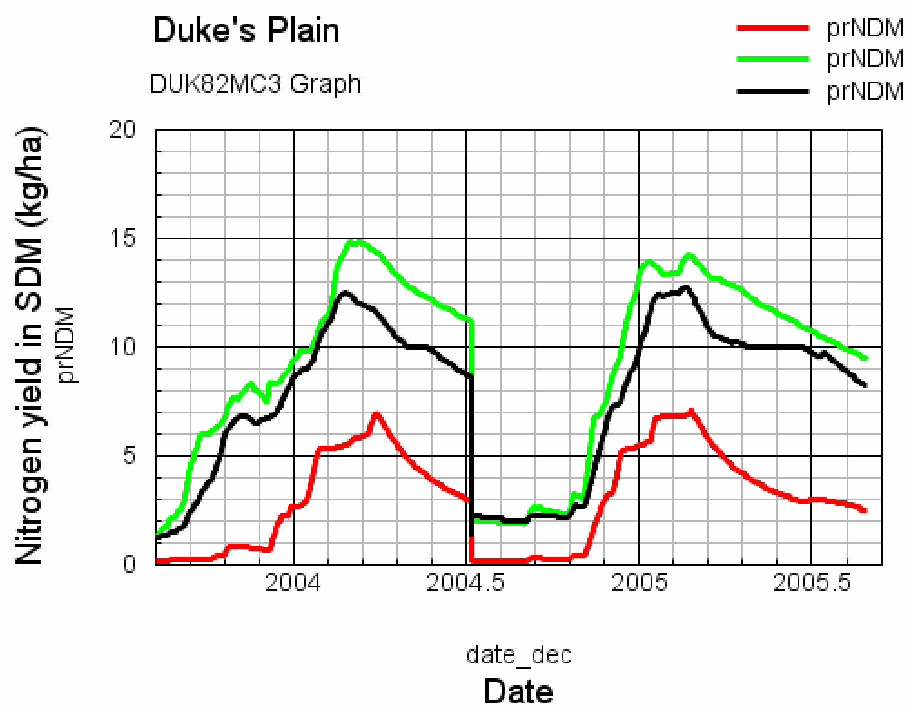


Figure 4.6.30. The time series of nitrogen yield in SDM (kg N/ha) for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

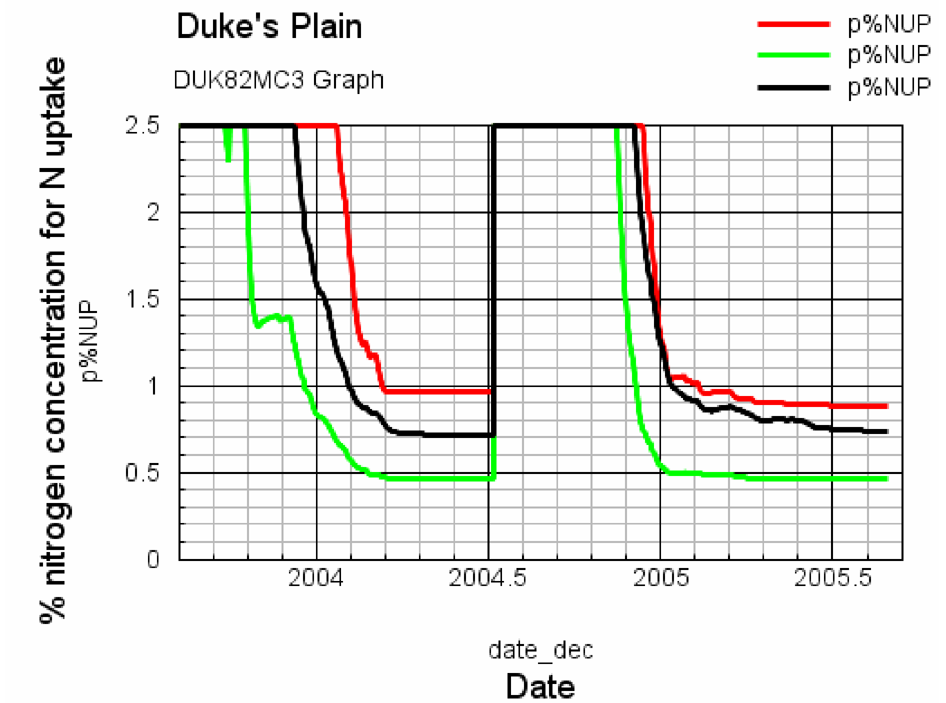


Figure 4.6.31. The time series of % nitrogen concentration from N uptake for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

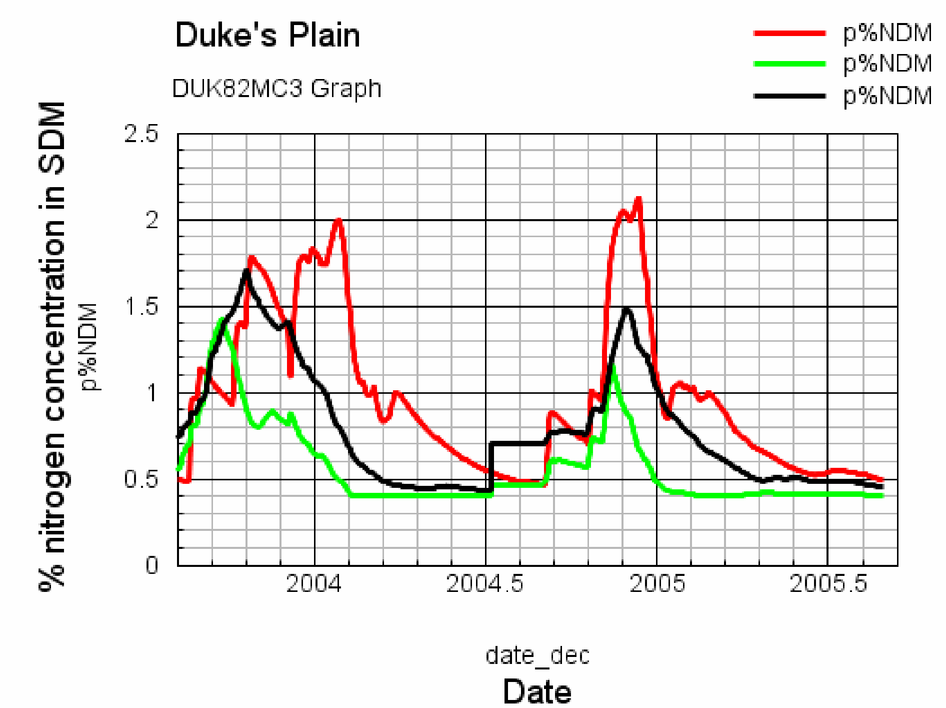


Figure 4.6.32. The time series of % nitrogen concentration in SDM for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

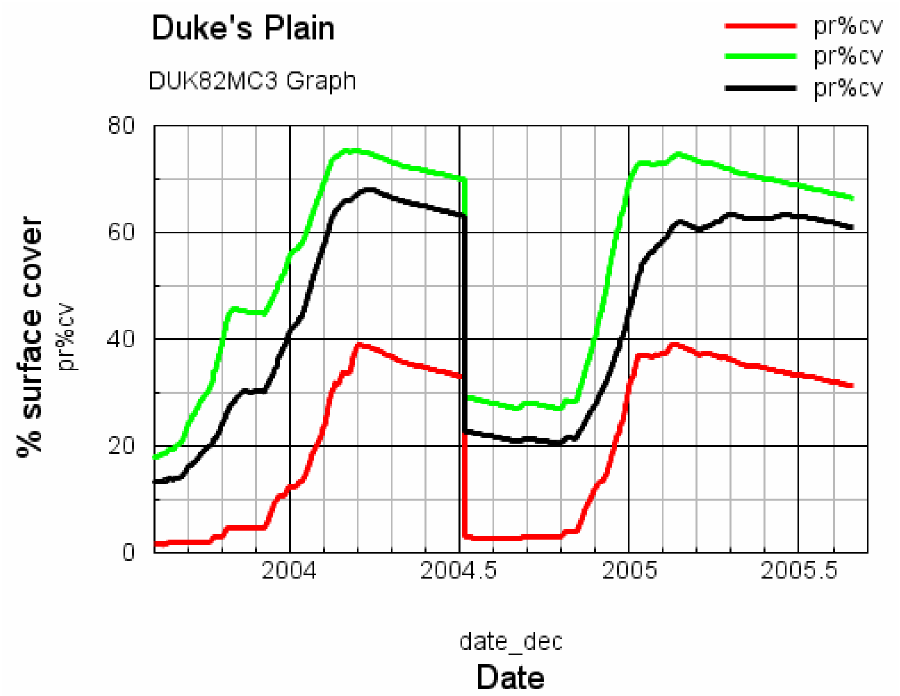


Figure 4.6.33. The time series of % surface cover for three positions along the pasture transect: 21 metres in the middle of the tree strip (red line); 40 metres (2 x tree height from tree strip edge) at the location of peak pasture yield (blue line); and 87 metres (i.e at the end of Zone 6, black line).

4.6.3.3 Alternative parameters describing fertility at Duke's Plain

In the pasture model GRASP, the key parameters that control potential annual pasture growth are maximum nitrogen uptake (p099) and minimum nitrogen concentration (p101). These parameters allow a calculation of potential pasture growth by the following simple equation involving maximum N uptake (kg N/ha) divided by minimum nitrogen concentration (%N).

$$\text{Potential pasture growth} = \frac{\text{maximum N uptake}}{\text{minimum \%N/100}}$$

The values used in previous parameterisation were derived from measurements taken in May 2005 estimating maximum nitrogen uptake as 19kg N/h and minimum nitrogen concentration varying from 0.70 in Zone 6 to 0.42 for Zone 2 (Figure 4.6.34a). An alternative view of these parameters can be derived from the land type analysis being conducted as part of the Grazing Land Management Education Package (C. Chilcott personal communication), and the GUNSYNpD/SWIFTSYNpD parameter set (Day *et al.* 1997). These data sets and modelling analyses suggest that a higher maximum nitrogen uptake was likely on Brigalow soils (28kg N/ha). Day *et al.* 1997 used a minimum nitrogen concentration of 0.68 for the calibration of buffel grass on Brigalow soils.

Thus there are two possible representations of fertility parameters for Duke's Plain namely: (a) 'average fertility' with maximum nitrogen uptake at 19kg N/ha and minimum nitrogen concentration ranging from 0.42 to 0.70; and (b) a 'high fertility' parameter set with maximum nitrogen uptake of 28kg N/ha and minimum nitrogen concentration ranging from 0.48 to 0.70. Figure 4.6.34a shows minimum nitrogen concentration along the transect using these different approaches to estimate minimum nitrogen concentration. The calculation of potential pasture growth is shown in Figure 4.6.34b. Although the values using the 'average fertility' parameter set are in close agreement with the observations of pasture standing dry matter, issues of water limitation and detachment of pasture standing dry matter have to be considered.

It is important to recognise the difference between accumulated pasture growth and pasture standing dry matter measured at the end of the growing season. Pasture standing dry matter is the result of the processes of growth and the losses through detachment and animal intake. Where growth stops early in the growing season e.g. January then measurements made in May are likely to underestimate seasonal pasture growth because of pasture detachment. In the above simulations we have used a relatively high rate of detachment (0.004 kg/kg/day) consistent with other parameterisations for buffel grass (Day *et al.* 1997). Figures 4.6.35a,b compare simulated pasture growth with pasture standing dry matter for the two years at Duke's Plain. In the zone of maximum growth (40m on the transect) there was substantial difference between accumulated pasture growth and pasture standing dry matter in mid-May. However, the difference was less within the tree strip and at the end of the transect in open pasture as a result of the delay in reaching peak standing dry matter and the onset of senescence at these transect locations (Figures 4.6.25 and 4.6.27). In future analysis verification of the difference in detachment rates along the transect will be evaluated with the cover data and the transect photos. The simulations suggest that large effects on standing dry matter are possible along the transect due to different detachment rates and this aspect of the effect of tree strips should be further evaluated.

Figure 4.6.36 shows the comparison between measured and simulated pasture components along the pasture transect using the 'high fertility' parameter set. Agreement is similar to that using the average parameter set highlighting the fact that a range of parameter sets can provide similar agreement with observed data. It was judged that the 'high fertility' parameter set provides a more reasonable basis for conducting simulations over 100 years and is more likely to represent pasture growth under water non-limiting situations in above-average rainfall years.

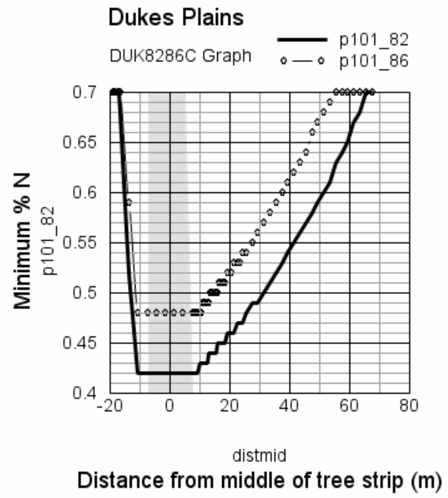


Figure 4.6.34a. Along the pasture transect, minimum nitrogen concentration parameter used in two studies at Duke's Plain: Average fertility using site observation (solid line) and high fertility with buffel grass parameters (open circles).

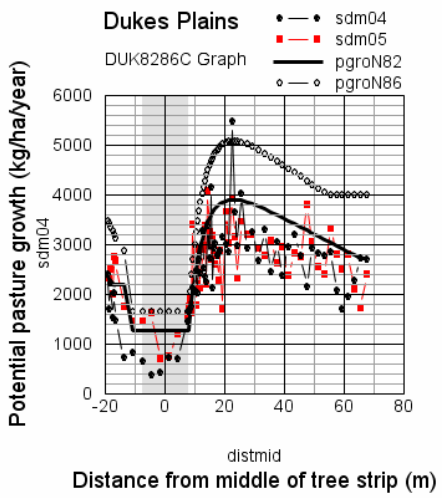


Figure 4.6.34b. Along the pasture transect, potential pasture growth for two levels of fertility (average and high) and two minimum nitrogen concentration parameters (site observation, buffel grass).

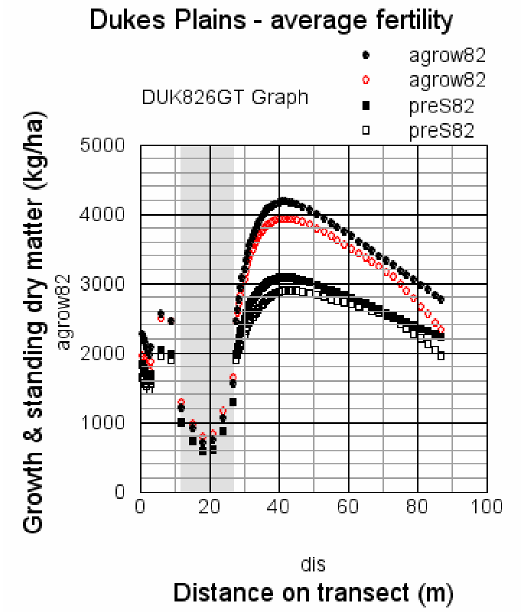


Figure 4.6.35a. Along the pasture transect, simulated growth (circles) and pasture standing dry matter (squares) for average fertility parameters at Duke's Plain for 2004 (solid) and 2005 (open).

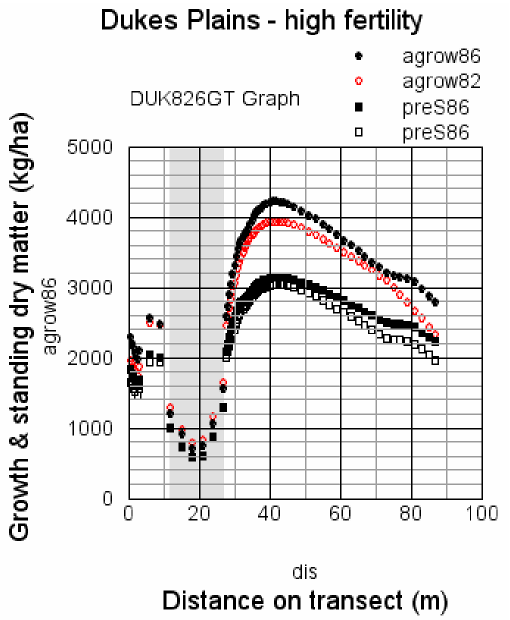


Figure 4.6.35b. Along the pasture transect, simulated growth (circles) and pasture standing dry matter (squares) for high fertility parameters at Duke's Plain for 2004 (solid) and 2005 (open).

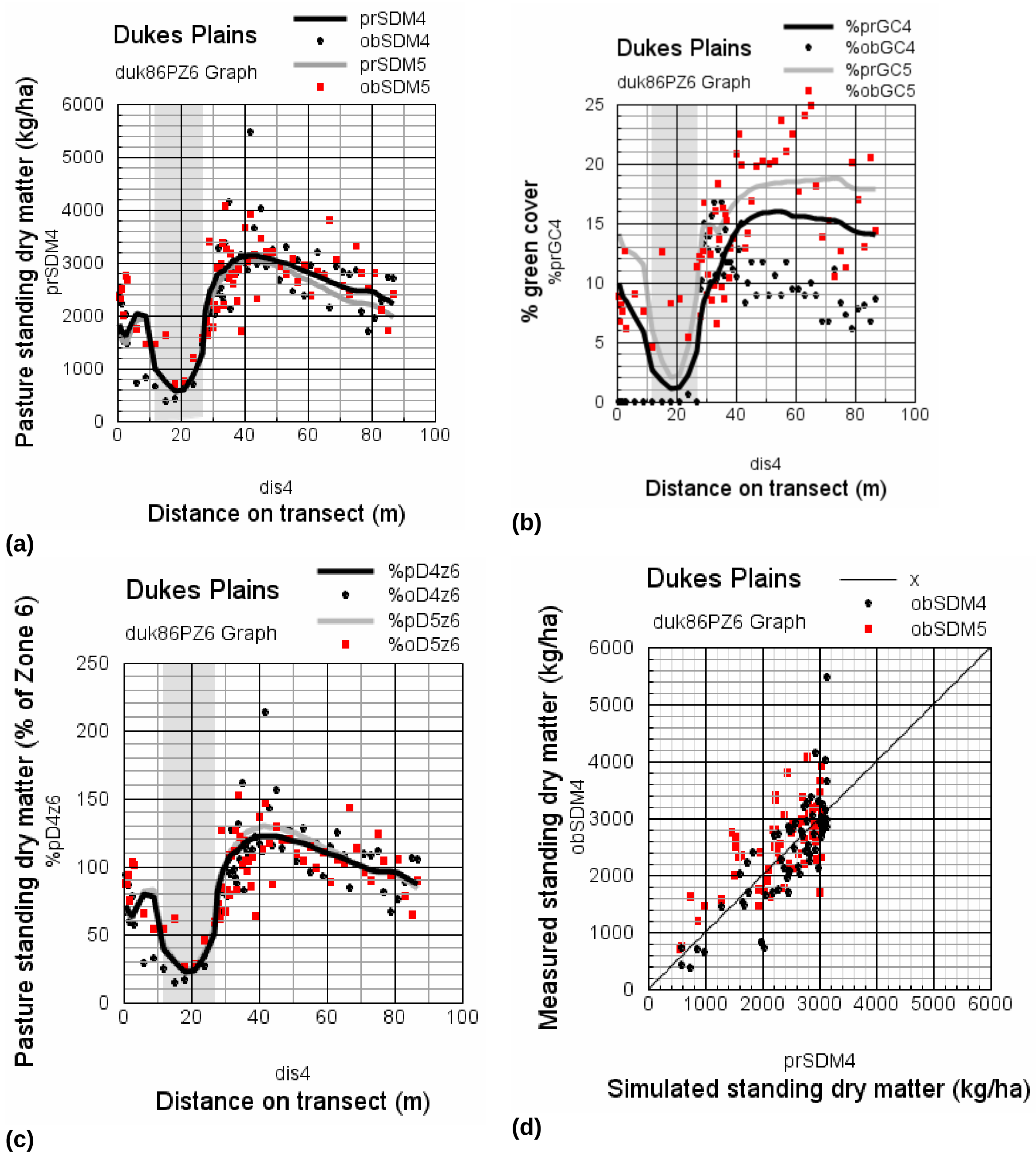


Figure 4.6.36. For high fertility parameter set at Duke's Plain for each season (2004, 2005), measured and simulated pasture components along the pasture transect (0 metres at start of Zone 1): a) pasture standing dry matter; b) % green cover; c) pasture standing dry matter as a percentage of Zone 6; and d) comparison of measured and simulated pasture standing dry matter. Symbols are: simulated 2004 (solid black line); simulated 2005 (solid grey line); measured 2004 (solid black circle); and measured 2005 (solid red square).

4.6.3.4 Simulation using long term climate data

The empirical relationships derived in Section 4.5 are specific to years and location of the field data. To achieve the objective of extrapolating the field results over time and space, the GRASP pasture growth model was parameterised along the pasture transect (as described above) allowing the effects of different sequences of daily climate (e.g. historical climate data) to be evaluated. The GRASP parameters determine the daily response of pasture growth, tree and pasture water use and tree competition for water and nitrogen. The parameters provide a reasonable representation of the field results in 2004 and 2005, and hence a sound basis for longer term simulations.

Simulations were conducted using over 100 years (1890 to 2005) of daily climate data for Cracow Store (Bureau of Meteorology Station No. 39028) 25km from the Duke's Plain field site. Duke's Plain rainfall data have been used in the simulation from December 1998. The source of the daily climate was the SILO climate data base which uses spatial surfaces of daily climate data derived from observations to estimate daily climate values at any location (Jeffrey *et al*. 2001). The simulations represent the effects of historical rainfall and to a lesser extent temperature and other climate variables. However, there are no historical time series of wind run and direction which would allow a better historical assessment to be made by the effects of tree strips. Thus the lack of historical wind data, and the explicit link of pasture growth parameters to variation in wind run and direction remains a major limitation in conducting the following historical simulations.

The pasture management 'rules' used in the long-term simulation were similar to the field trial with pasture SDM reset each year on 31 July to the estimated reset SDM yields calculated for 2004 (commencement of exclosure after several years of grazing). Simulations were conducted for each position along the transect where quadrat yields were measured.

Figures 4.6.37 show the average over 115 years (1891 to 2005) of climate, soil water balance and pasture components. Pasture 'pan' evaporation (Figure 4.6.37) was calculated from VPD and solar radiation estimated in SILO using CLIMARC and observed climate datasets, and modified with wind factor as indicated in Section 4.6.3.1 (Figure 4.6.8a and e).

The simulation analysis of the 115 years allows the two years of field measurements 2004 and 2005 to be ranked in the context of the longer experience of historical climate variability. For the 115 years at Cracow, rainfall for the 12 month periods ending 1 June 2004 and 2005 was ranked 50 and 30 respectively (Rank 1 was the driest year). Thus in terms of rainfall the field trial period represented drier than average conditions. However, distribution of seasonal rainfall and differences between Duke's Plain and Cracow in individual years are also likely to influence the precise ranking.

The patterns of water balance components (tree transpiration, pasture transpiration) and simulated through-drainage below the main tree zone (200cm depth) reflect the parameterisation of tree root distribution along the transect as well as pasture pan evaporation. GRASP calculates through-drainage simplistically, i.e. when infiltration into a soil layer exceeds the nominated field capacity. The actual mechanisms and magnitudes of through-drainage are far more complex than this simple approach and hence the simulated drainage values indicate only relative effects. The lower through-drainage values at the start of the transect compared to the end (Zone 1 at 0m, and Zone 6 at 87m) may be due to the combined effect of no tree roots and the lower pan evaporation at Zone 6 relative to Zone 1.

The peaks in transpiration and pasture growth at transect positions 50 and 40 metres respectively (≈2-4 x tree height from edge of canopy) reflect the favourable conditions for development of pasture cover in this zone. Simulated pasture growth along the pasture transect was very similar to that simulated for the two years at Duke's Plain indicating that field results could be regarded as reasonable estimates of the average effects of tree strip considering longer periods of climatic variability.

Figure 4.6.38 compares the long term simulation of pasture standing dry matter (1 June) averaged over 115 years with the measurements in 2004 and 2005. Both average and high fertility sets were considered. The long term average pasture standing dry matter was close to the values measured in 2004 and 2005 suggesting that the field measurements represented average climatic effects as integrated through the pasture growth model. Figure 4.6.39 shows the time series of pasture standing dry matter (1 June) from 1891 to 2005. Measured values for 2004 and 2005 represent average values compared to the wetter periods of the early 1890s, late 1900s, 1940s, 1950s and 1970s. The historical time series also indicates extreme droughts such as 1902, 1915 and 1920. As indicated above a limitation of the simulations is the lack of historical wind run data and links between seasonal wind run (and direction) and pasture growth parameters.

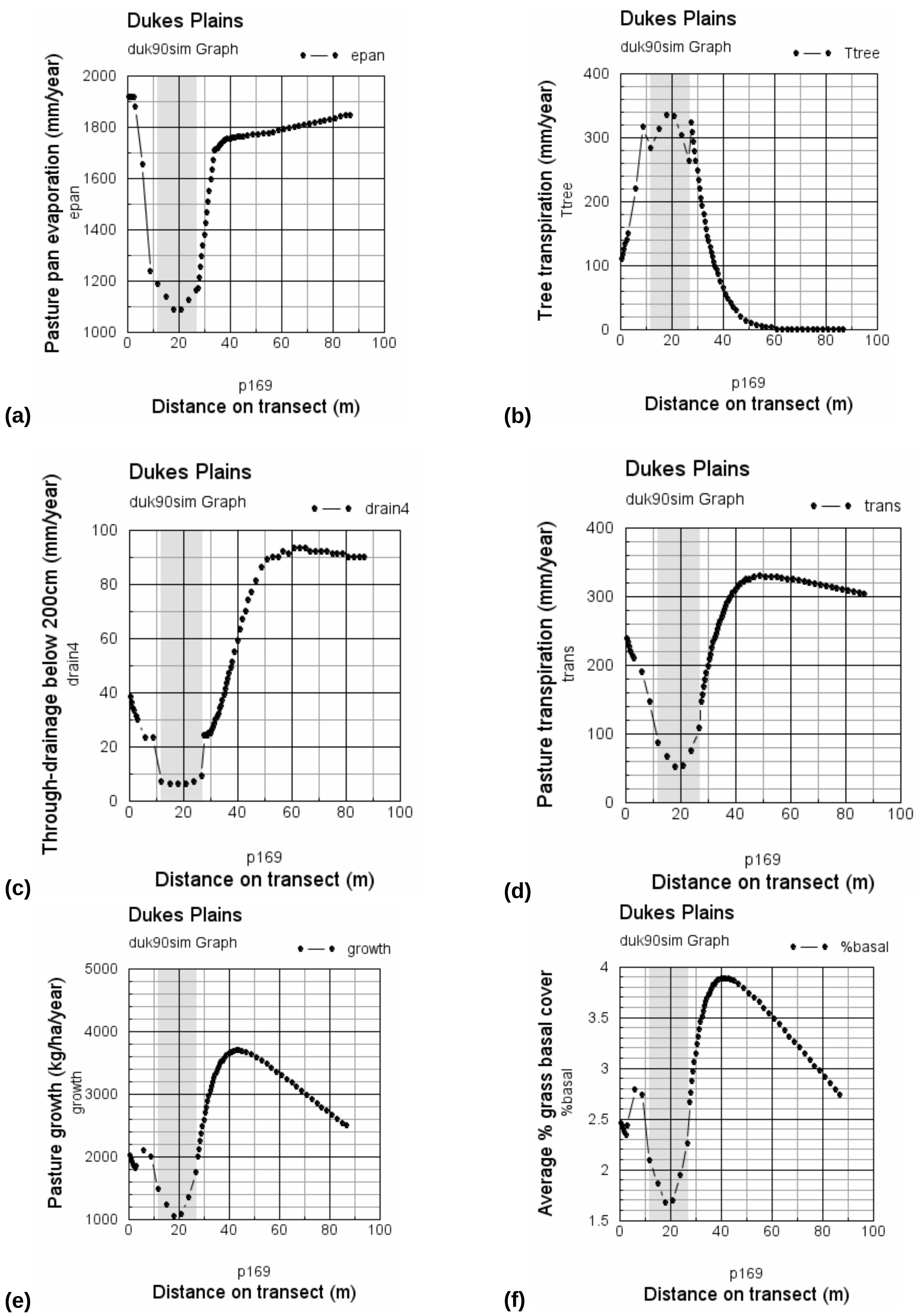


Figure 4.6.37. For the high fertility parameter set at Duke's Plain, simulation results of climate, soil water balance and pasture components: (a) calculated pasture pan evaporation; (b) tree transpiration; (c) through-drainage below 200cm; (d) pasture transpiration; (e) pasture growth; and (f) grass basal cover. Values are for 12 months averaged over 115 years from 1891 to 2005.

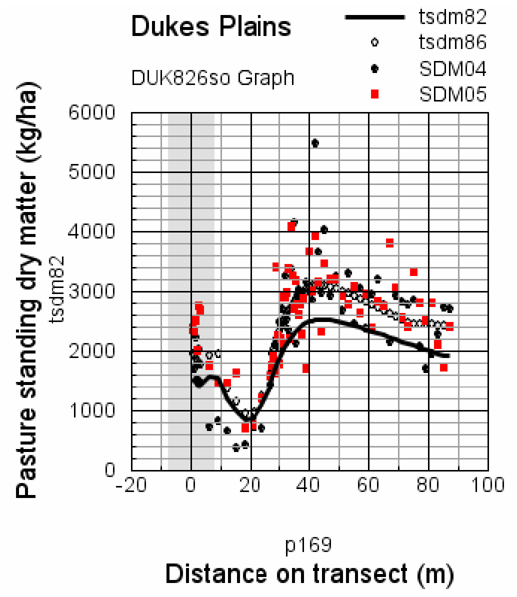


Figure 4.6.38. Comparison of long term simulation of pasture standing dry matter at Cracow using the average and high fertility parameter set, and observed SDM at Duke's Plain. Simulated SDM with average fertility (solid line), simulated SDM with high fertility (open circles), observed SDM in 2004 (solid circle), observed SDM in 2005 (solid red square).

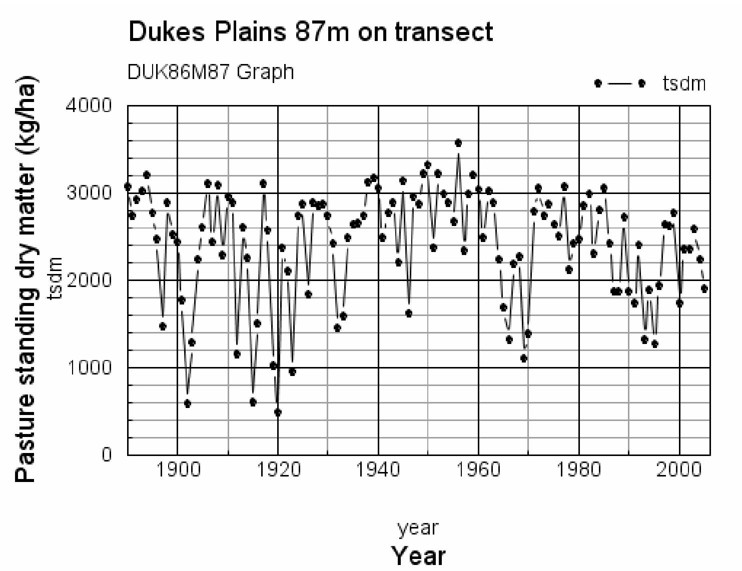


Figure 4.6.39. For the high fertility parameter set the simulation of pasture standing dry matter at Cracow for 115 years (1891-2005). The simulation is for the parameter set estimated at the end of the transect i.e. 87 metres. Pasture SDM was reset at the end of July in each year. Values shown are for the 1 June in the following year.

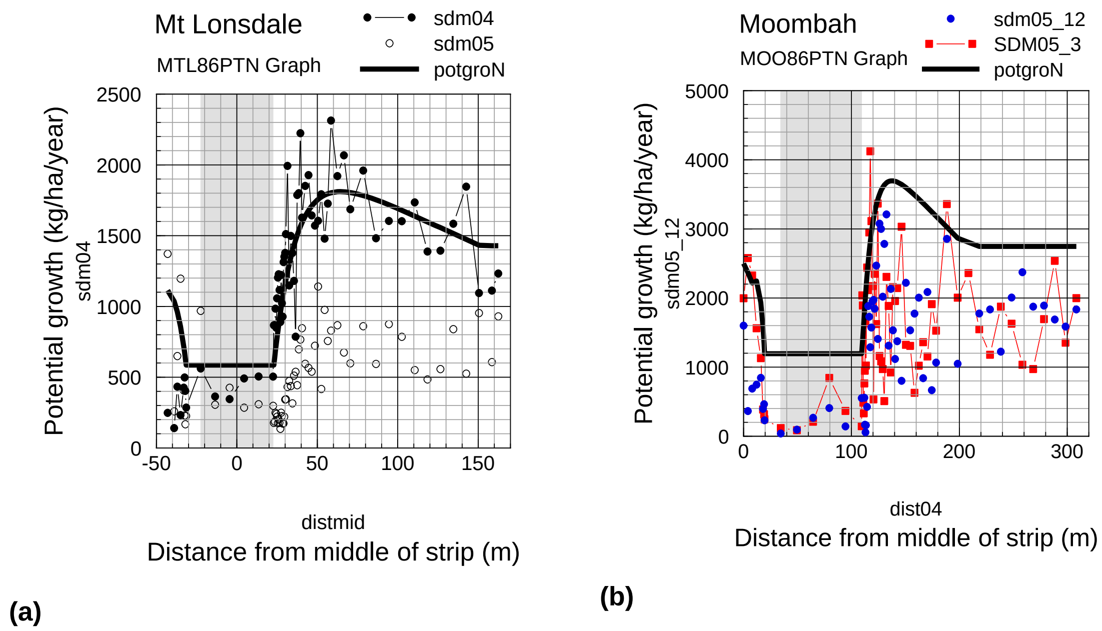


Figure 4.6.40. Comparison of potential annual growth (solid line) calculated from fertility parameters and SDM observations at Mt Lonsdale (a) and Moombah (b). Mt Lonsdale SDM 2004 (solid circles), Mt Lonsdale 2005 (open circles); Moombah 2005 average of southern aspect transects (blue circles), Moombah 2005 northern aspect transect (red squares).

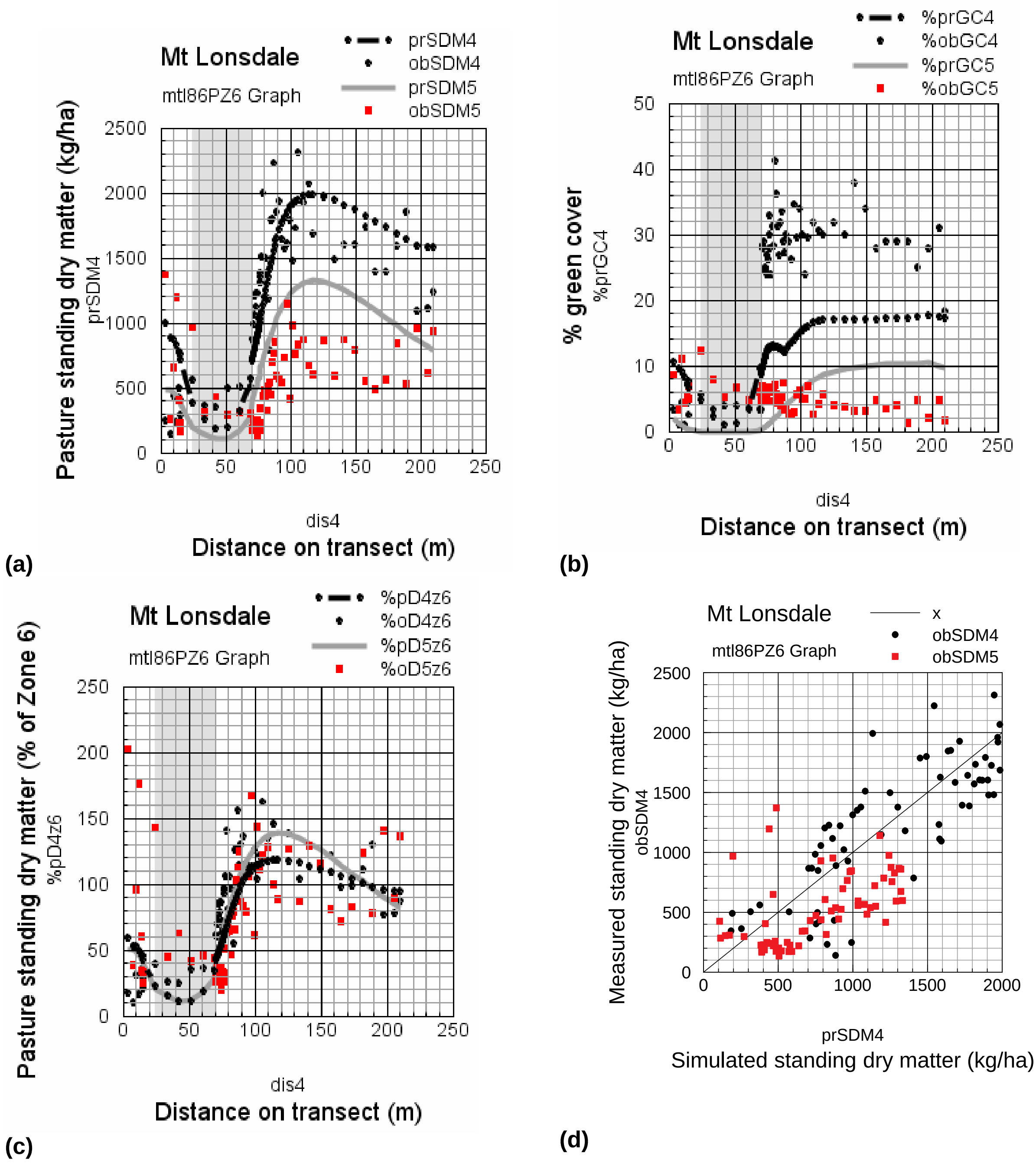


Figure 4.6.41. For a low fertility parameter set at Mt Lonsdale for each season (2004, 2005), measured and simulated pasture components along the pasture transect (0 metres at start of Zone 1): (a) pasture standing dry matter; (b) % green cover; (c) pasture standing dry matter as a percentage of Zone 6; and (d) comparison of measured and simulated pasture standing dry matter. Symbols are: simulated 2004 (solid black line); simulated 2005 (solid grey line); measured 2004 (solid black circle); and measured 2005 (solid red square). The parameter set was as for Duke's Plain Section 4.6.3.1 with changes to potential nitrogen uptake based on SDM measurements in 2004.

4.6.4 Application to other locations

The following section describes the application of the parameterisation developed for Duke's Plain to Mt Lonsdale and Moombah datasets. The approach adopted was to estimate site characteristics from the field data that were also consistent with the land type analysis (C. Chilcott personal communication) referred to earlier. The model of parameters along the pasture transect developed for Duke's Plain calculated the impacts of tree strips as a multiple of tree height from the edge of the tree strip. Hence in the following applications, tree height specific to the other locations was used (Table 3.3.1.2). Similarly the attributes of the tree strip such as width and tree basal area were also changed. The measurements of temperature differences along the transect measured at each zone at Mt Lonsdale and Moombah (Tables 4.1.4 – 7) were input. Thus the following simulations provide a test to some extent of the generality of the model developed specifically for Duke's Plain but using site information on climate data and potential pasture growth estimated from the field measurements. Major limitations to parameterisation at other locations were the lack of wind measurement and the possible effects of systematic variation in soil disturbance and surface soil characteristics.

Although there were similar relative effects of tree strips on pasture growth at Duke's Plain and Mt Lonsdale, there were large differences in measured pasture microclimate effects (see Section 4.1). More detailed work is required to reconstruct daily pasture microclimate data, and especially deriving wind and evaporative demand effects from the temperature differences along the pasture transect.

As indicated in previous sections (Sections 4.1, 4.5), pasture transects at Mt Lonsdale varied from Duke's Plain in terms of aspect and tree density. Furthermore, there was evidence for the potential run-on from grazed zones outside the exclosure at Zone 6, soil surface condition in Zones 2 and 3 suggest these areas are potential runoff generating areas. At this stage of the analysis, there are insufficient wind run and direction data to apply a specific wind effect parameterisation. Furthermore the lack of detailed micro relief limits estimation of water redistribution to different zones associated with individual tree strips. Nevertheless, the average pattern of growth (measured as SDM) was similar in relative terms to Duke's Plain (Section 4.5). Thus, as a first simulation example, the general model of parameter change along the transect, described in Section 4.6.3.1, has been used.

Figure 4.6.40 indicates potential pasture growth calculated from maximum nitrogen uptake and minimum nitrogen concentration. In the case of Mt Lonsdale, maximum N uptake was estimated from 2004 SDM data at 10kg N/ha indicating a low fertility site in terms of the land type analysis. Minimum nitrogen concentration was set at 0.68%N (average native pasture parameter value). At Moombah, maximum N uptake was estimated from field measurements at 30kg with a minimum nitrogen concentration of 1.0%. The high fertility of Moombah is also supported by the fact that grain cropping was considered as an alternative land use for the site.

Figure 4.6.41 shows the results of simulation with the low fertility parameter set at Mt Lonsdale. There was reasonable agreement with measurements in 2004 when nitrogen was likely to be limiting pasture growth (e.g. Figure 4.6.40). However, measurements for Mt Lonsdale in 2005, a drought year, did not show the same pronounced enhanced effect of the tree strip on the open pasture component of the transect (100-120m) as occurred in 2004. An additional simulation was conducted in which only the effect on minimum nitrogen concentration was considered. The other pasture growth parameters (transpiration efficiency, radiation use efficiency, water use efficiency) were held constant across the transect. The simulation results showed that with this parameterisation the enhanced effect of the tree strip occurred in 2004 but not in the water-limited year of 2005. In the latter year, the simulation better represents the measured data. The year 2005 at Mt Lonsdale was the driest year of the five year-by- location combinations measured in this study. The results suggest that the interaction of tree strip effects on pasture growth parameters and year type should be further investigated.

Simulated green cover did not agree well with observed green cover. As discussed for Duke's Plain green cover is likely to be affected by soil water stress and frost occurrence and further model calibration is required to improve the representation of pasture senescence.

The Moombah tree strip data set was divided into two sets. Strips 1 and 2 had a pasture transect with a southern aspect whilst the pasture transect at tree strip three had a northern aspect. The possible impact of this difference in orientation is shown in the effect on standing dry matter and green cover (Figure 4.6.43a,b). In the case of the southern aspect, the peak in standing dry matter was at 132.5m (22.5m from the tree strip edge). In contrast for the northern aspect transect the peak was closer to the tree strip (at 117.5m or 7.5m from the strip edge). Tree height was estimated at 12-20 metres depending on the species components of tree strips that were likely to affect pasture growth. Thus the field results suggest that shading has an impact on pasture growth in the immediate vicinity of the tree strip and supports the parameterisation of increased pasture growth parameters in this shaded zone (Section 4.6.3.1).

Figure 4.6.44 shows application of the Duke's Plain parameterisation at Moombah. The rainfall data used in the simulation were derived from the SILO data drill and hence are dependent on measurements taken tens of kilometres away from the site. The use of SILO rainfall estimates provides a first basis for evaluating the Moombah data. The transect pasture SDM data was highly variable and included the effects of ash beds and other possible discontinuities due to different ages of pasture establishment. Once reconstruction of climate data has occurred using homestead data and transect variation (pasture density and ash beds) have been 'parameterised' further simulations should be conducted. As a consequence the Moombah SDM data show high variability along the transect. Preliminary simulations indicated that the average fertility set generally underestimated the high values of standing dry matter along the transect. The following changes to the average fertility parameter set were made:

1) maximum nitrogen uptake was increased to 30kg N/ha;
2) minimum nitrogen concentration was set to 1% based on measurements made in 2005;
3) transpiration efficiency was increased from 13.5 to 20kg/ha/mm; and
4) potential pasture regrowth rate was increased from 3.5 to 5.2 kg/ha/day per unit of GBA.

Variability in tree height of components the Moombah tree strips was an important source of uncertainty that was considered in the application of the transect parameter model. The highest tree component (poplar box) had a height of >20m with several tall late maturing trees emerging from the dominant shrub layer (8-12 metres height). The length of the sampled pasture transect (≈200m from strip edge) was determined using the higher tree height (20m). However, for model parameterisation and analysis (Section 4.5), the lower height of the more dominant shrub layer was used (12m) to evaluate the potential beneficial and competitive effects in terms of tree height. As a consequence, the simulated transect was substantially longer than the other locations in terms of multiples of tree height.

The pattern of simulated SDM along the Moombah transect had a distinct peak at 130m (20 metres from strip edge), a decline to 200m (90 metres from strip edge), and a plateau in SDM from 200 to 300m (90-190 metres from strip edge). However, the SDM measurements had very high variability between adjacent quadrats with evidence of soil disturbance and ash beds. More detailed interpretation of SDM measurements will require further analysis of transect photos and other measurements (e.g. Appendix 10.9). Nevertheless, the simulations show a distinct peak at 130m, the same distance as the measured peak on the southern aspect transect.

4.6.5 Conclusion

The studies reported in Section 4.5 and 4.6 represent the initial analyses of the transect data from a modelling viewpoint. As such these analyses have provided a different emphasis of components of the large amount of data, collected in the study. The analyses have revealed important uncertainties to be addressed in future analyses and field data collection.

The preliminary sensitivity study (Table 4.6.7) indicated the importance of parameterising minimum nitrogen concentration, transpiration efficiency and solar radiation interception along the pasture transect. The next step is link these parameters with the biophysical effects of tree strips along the pasture transect. At Duke's Plain, the difference in pasture species composition between replicates could have had an important effect on pasture growth. In a future analysis, individual replicates will be analysed in terms of the position of pasture species on the transect, and will then be tested with the GRASP model using different parameters for each pasture species.

The above simulation study used the Duke's Plain wind run measurements to parameterise a general asymmetrical effect of the tree strip on wind run and calculated pan evaporation (Figure 4.6.8). Variation in wind direction, synoptic conditions, tree strip orientation are all likely to influence the spatial distribution of tree strip influences and hence a caveat on the above simulations is that they are specific to the effects on wind run measured at a single Duke's Plain tree strip in 2004.

The analyses described above provide an initial perspective of the representation of tree strip effects using the GRASP model. The main parameterisation of climate and pasture features along the pasture transect was derived for Duke's Plain, and was tested with data collected at Mt Lonsdale and Moombah with modifications based on site specific attributes (fertility, climate effects).

The simulation study is far from complete. To address identified limitations further analyses include:

1) extensive sensitivity analysis on each GRASP parameter to evaluate the contribution of each component in terms of beneficial and competitive effects;

2) simulations with wind break models to construct alternative representations of wind and shading effects on climate variables such as temperature and pan evaporation;
3) reconstruction of regional daily meteorology for the field experiment period with particular attention to wind run, wind direction and cloud cover;
4) alternative representations of tree strip effects on parameters as discussed in Section 4.5 and Appendix 10.7 including the derivation of parameters such as transpiration use efficiency, radiation use efficiency and minimum nitrogen from physiological principles;
5) inclusion of measurements of soil moisture, green and total cover, and photo analysis of grass basal area (cover) in model calibration including possible changes in available water range and pasture detachment rates along the transect; and
6) analysis of systematic soil variation along the pasture transect resulting from soil disturbance and natural micro relief features.

The last word

This final report describes the detailed field work carried out in 2004 and 2005 at three separate locations. At each location, three tree strips were studied in terms of their effect on pasture growth along the transect perpendicular to the tree strip. Supporting data on climate, soil, and other vegetation attributes were collected. This report details the first analysis of this information and the initial empirical and simulation modelling derived from this analysis. As such, the final report represents the completion of the initial phase of field work, data analysis and simulation modelling. The next phase of the study can build on this analysis and address many of the issues raised by the first phase of the study.

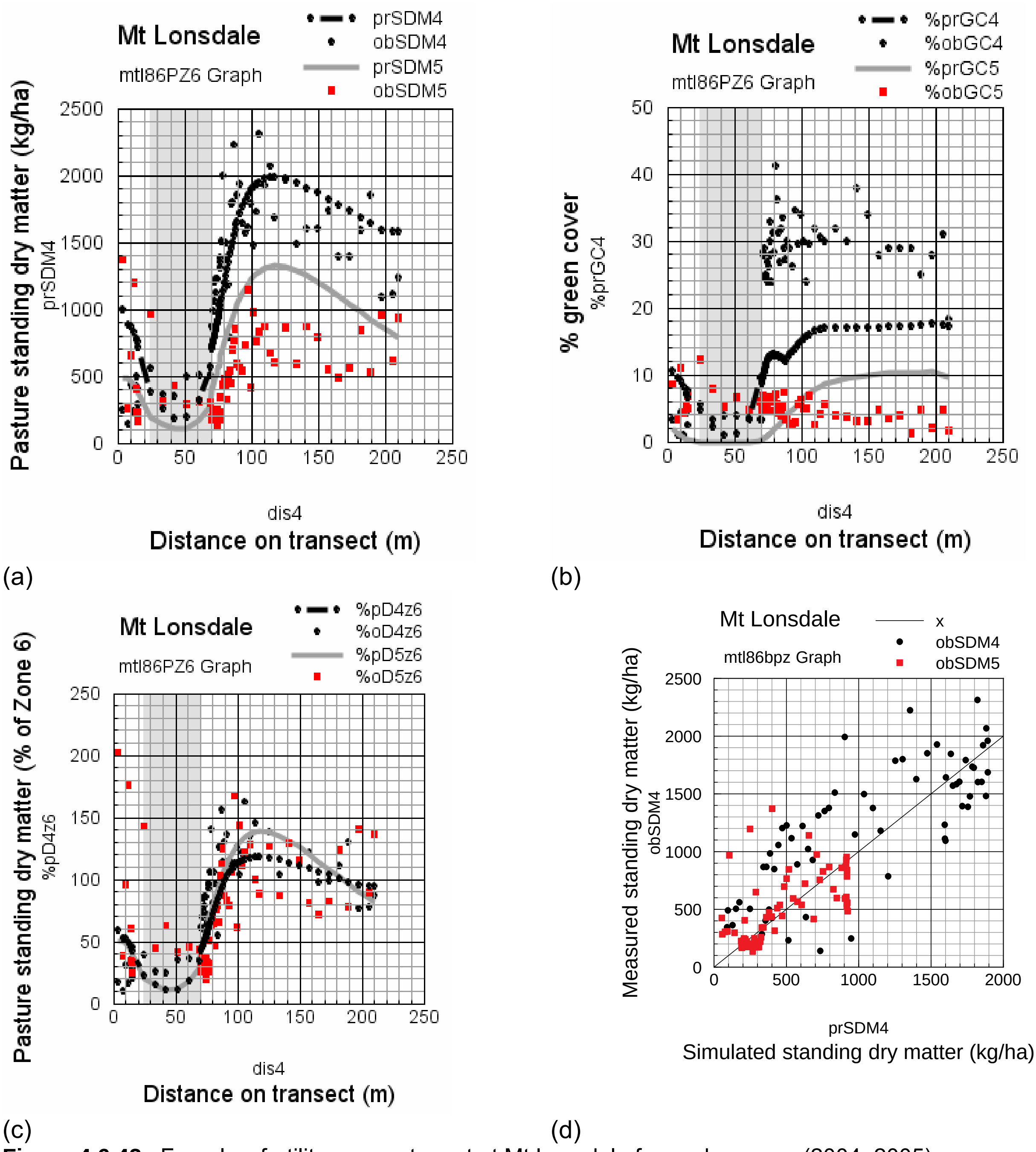
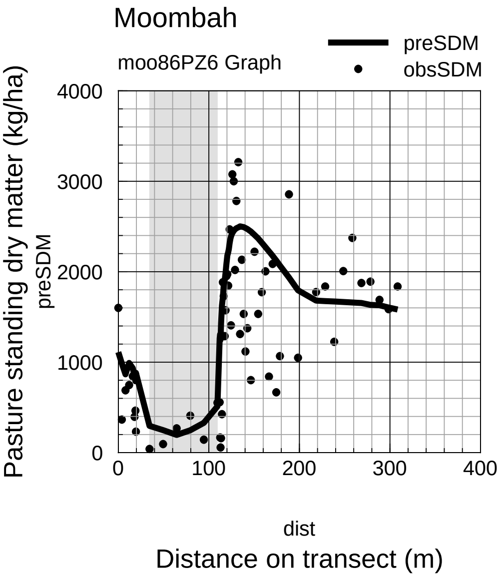
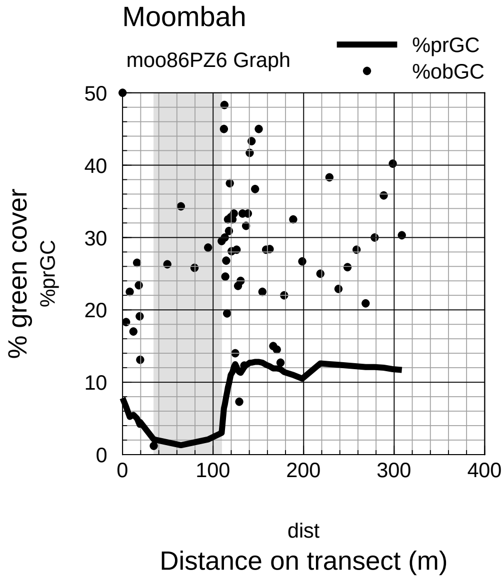


Figure 4.6.42. For a low fertility parameter set at Mt Lonsdale for each season (2004, 2005), measured and simulated pasture components along the pasture transect (0 metres at start of Zone 1): (a) pasture standing dry matter; (b) % green cover; (c) pasture standing dry matter as a percentage of Zone 6; and (d) comparison of measured and simulated pasture standing dry matter. Symbols are: simulated 2004 (solid black line); simulated 2005 (solid grey line); measured 2004 (solid black circle); and measured 2005 (solid red square).The parameter set was as for Duke's Plain Section 4.6.3.1 with changes to potential nitrogen uptake based on SDM measurements in 2004. The major difference from simulations shown in 4.6.41 was that, of the various pasture growth parameters, only minimum nitrogen concentration was changed along the transect.

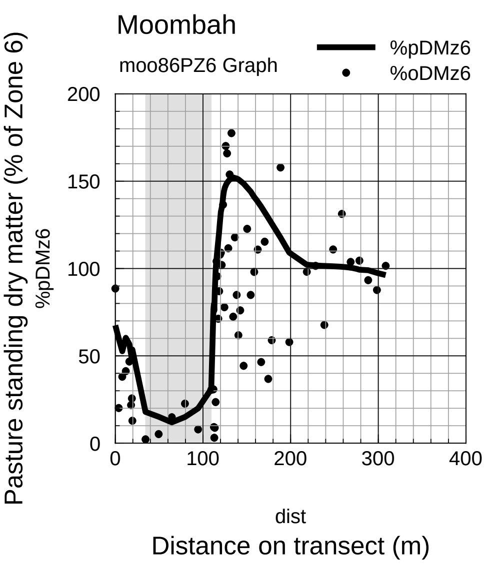
Figure 4.6.43 a,b,c,d. For Moombah in 2005 measured pasture components along the pasture transect for southern and northern aspect transects. The pasture components are: (a) pasture standing dry matter; (b) percentage green cover; (c) percentage total standing cover and (d) percentage litter cover. Southern aspect transect is the average of tree strips 1 and 2 (blue circles). The northern aspect transect is tree strip Replicate 3 (red squares).



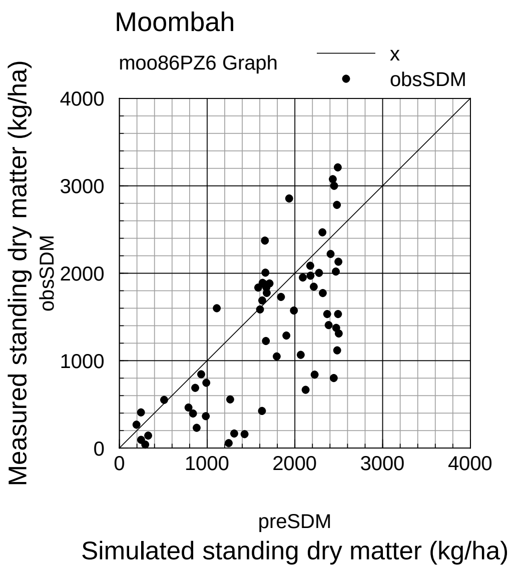
(a)



(b)



(c)



(d)

Figure 4.6.44: At Moombah for 2005 measured (solid circles) and simulated (solid line) pasture components along the pasture transect (0 metres at start of Zone 1): (a) pasture standing dry matter; (b) % green cover; (c) pasture standing dry matter as a percentage of Zone 6; and (d) comparison of measured and simulated pasture standing dry matter. The parameter set was as for Duke's Plain (Section 4.6.3.1) with changes to potential nitrogen uptake and transpiration efficiency based on SDM measurements in 2005.

5 Success in Achieving Objectives

5.1 Success in Achieving Objectives

The objectives of the project were to:

1) Define in quantitative terms the beneficial and competitive effects of trees on surrounding grazing systems in southern Queensland;
2) Develop the modelling capacity (within the GRASP growth model) which will enable evaluation of the impacts of different tree and regrowth configurations and management on the grazing systems in terms of productivity and sustainability; and
3) Develop and publish tree and grass management guidelines and associated extension and education materials for beef producers and distribute the publications.

Objective 1 was met through detailed measurements of the effects of tree strips on three grazing properties in southern Queensland. Measurements were taken along pasture transects perpendicular to three tree strips at each location. The effects of tree strips along the pasture transect was quantified in terms of pasture microclimate, pasture growth in grazed and exclosed situations, soil water, soil nutrients, soil surface condition, and nutrient availability. An experimental approach using exclosed pasture transects provided a useful ‘bioassay’ integrating beneficial and competitive effects on pasture growth.

The field results for five locations x year combinations demonstrated zones where different competitive and beneficial effects dominated in terms of pasture growth. However, a recognised limitation of the study was the lack of understanding of possible systematic variation with soil disturbance or natural landscape features associated with the retention or positioning of tree strips.

The project highlighted the difficulty of researching the impact of tree strips in the real world given the large number of variables and the resources required to maintain equipment and field sites.

Objective 2 was met through the modification of the soil water-pasture growth model GRASP. Following a detailed review of other models, a new version of GRASP was developed allowing simulation of tree and pasture effects and processes for each position (e.g. 0.5 metre) along the pasture transect. Model parameters along the transect described:

(a) pasture microclimate effects of the tree strip such as on wind, solar radiation (i.e. shading), potential evapo-transpiration, and air temperature and humidity;
(b) tree and pasture uptake of soil water and nitrogen;
(c) pasture growth parameters such as the efficiency of transpiration, radiation and nitrogen use; and
(d) pasture senescence due to frost and water stress including effects of shading.

The model was developed on data from Duke's Plain and tested to a limited extent at the other locations. However, at this stage of analysis, it is not clear to what extent the individual tree strip and site attributes can be parameterised at the other two locations. The modelling study showed that a reasonable proportion of variation in quadrat pasture yields along the transect could be explained. However, the modelling study, documented in detail in the report, represents only the initial study. Model development will continue as the 'rich field' data set collected in this study is further analysed and interpreted.

Objective 3 was partially met through the detailed report describing this first study on the effects of tree strip in southern Queensland. Preliminary brochures describing the results at each site have been developed and some of the project results and principles have been included in the Grazing Land Management Education Package (C. Paton pers. comm.).

The detailed analysis of data and model development documented in this report also provided a powerful demonstration of the difficulty on researching complex tree-grass systems in real world (grazing property) situations. Nevertheless, the strength of the study is that this complexity has been addressed and documented through field measurements and in critical analysis of data.

6 Impact on Meat and Livestock Industry – now and in five years time

6.1 Impact on Meat and Livestock Industry – now and in five years time.

The first two objectives of the project were to quantify and model the results. This report documents the completion of these two objectives and provides a scientific basis for further extension of information to beef producers. The next stage of the program is to feed back the results to the individual producer co-operators and then based on the combined project analysis and grazier experience, develop practical extension information. The results of this project have the potential to influence the management of woody regrowth at a time (i.e. next five years) when graziers and government are most receptive to the information collected in this project. However, at this stage of the research, the results should not be used as a basis to formulate tree management guidelines or prescriptions. The caveats described in the report need to be included in any extension material.

As indicated below, a conclusion from this study is the need for a rapid assessment of as many tree strips as possible using the pasture bioassay approach demonstrated in this project as well as reporting and synthesising individual grazier experience. This approach would build a network of supporting data and experience covering the range of variability that occurs in real world situations.

7 Conclusions and Recommendations

7.1 Conclusions and Recommendations

The effects of tree strips along a pasture transect were quantified in terms of pasture microclimate, pasture growth in grazed and exclosed situations, soil water, soil nutrients and condition, and nutrient availability at three locations on grazing properties (Duke's Plain, Mt Lonsdale and Moombah). An experimental approach using exclosed pasture transects provided a useful 'bioassay' integrating beneficial and competitive effects on pasture growth.

The field results for five locations x year combinations demonstrated zones where different competitive and beneficial effects dominated in terms of growth. However, a recognised limitation of the study was the lack of understanding of possible systematic variation with soil disturbance or natural landscape features associated with the tree strips.

The detailed analysis of pasture standing dry matter measured in exclosures indicated zones of competitive and enhanced pasture growth compared to open pasture (i.e. at a maximum distance from tree strips). In terms of overall impact, the degree of enhancement at Duke's Plain and Mt Lonsdale compensated to some extent for the competitive effects of the tree strips. However, the causes of enhanced pasture growth in particular zones away from the tree strip are unclear. In addition to the possible beneficial effects of tree strips on pasture microclimate and nutrient availability, there were at each location different dominating effects apparent along the pasture transect: variation in pasture composition at Duke's Plain; fallen timber and micro-topography at Mt Lonsdale; and different times of pasture establishment and ash bed effects at Moombah. At this stage of the analysis, it is not possible to separate these effects from the potentially beneficial effects of the tree strip. As a consequence the results should not be extrapolated to general guidelines on vegetation management.

Following a detailed review of other models, a new version of the soil water-pasture growth model GRASP was developed allowing simulation of tree strip effects on tree and pasture biophysical and processes for each position (e.g. every 0.5 metre) along the pasture transect. Model parameters along the transect described:

1) pasture microclimate effects of the tree strip such as on wind, solar radiation (i.e. shading), potential evapo-transpiration and air temperature and humidity;
2) tree and pasture uptake of soil water and nitrogen;
3) pasture growth parameters such as the efficiency of transpiration, radiation and nitrogen use; and
4) pasture senescence due to frost and water stress including effects of shading.

The model was developed on data from Duke's Plain and tested at the other locations. The modelling study showed that a reasonable proportion of variation in quadrat pasture yield along the transect could be explained. The modelling study, which is documented in detail in the report, represents only the initial study. Model development will continue as the 'rich field data' set and grazier experience collected in this study are further analysed and interpreted.

The results from the project showed that tree strips had beneficial and competitive effects on adjacent pasture growth. These separate effects were represented in empirical and simulation models potentially allowing extrapolation to other year-types, locations and tree strip configurations.

There were several major limitations to the study and it is recommended that these limitations be addressed in future research to build on the scientific basis established in this project. The experimental approach developed and demonstrated in the project of using a pasture bioassay to integrate the competitive and beneficial effects of tree strips needs to be applied to a much greater number of tree strips covering variation in soils, tree density, tree species, pasture types, tree strip orientation and width and density of strips. This relatively simple experimental work would provide a basis for communication with graziers as well as extrapolating to other year-types and locations. Such experimental work would also address the major limitation of the possible influence in systematic soil disturbance (e.g. blade ploughing, stick raking and ash beds) and natural variation in soils associated with the retention or positioning of existing tree strips. The lack of understanding of these soil effects may lead to the incorrect attribution of tree strip effects in terms of competitive and beneficial effects on pasture growth.

The results of the project indicated that tree strips have important effects on pasture microclimate. However, the results also showed the difficulty in quantifying these effects over the range of variation that exists on extensive grazing properties. Previous national programs investigating the influence of wind breaks on pasture and crop production have led to the development of sophisticated models of pasture and crop microclimate to address this complexity. The next stage of this project should be to investigate the possible use of these models with regard to the three locations studied and extrapolation to other locations and configurations. Similarly a major limitation identified in historical climate data is the lack of information on wind run and direction. The collation and reconstruction of historical wind information will be an important step in extrapolating the project results in time and space and also anticipating the effects of climate change.

A feature of each of the trial sites was that the tree strips studied were not single features of the landscape, but were the woody components of a more fragmented mosaic of woodland areas and open pasture at each property. As such, the effects measured on pasture adjacent to the tree strips were likely to reflect both the immediately adjacent factors such as competition, shading, wind reduction, nutrient cycling as well as more general 'surface roughness' features associated with the mosaic of woody components. A greater number of woody components (e.g. tree strips), might amplify or reduce the impact of individual tree strips on adjacent pasture microclimate. However, given the available resources for this project, measurements concentrated on the impact of individual tree strips. Nevertheless, the future opportunity exists at each location to compare the larger scale impacts of a mosaic of retained woody vegetation in comparison to adjacent completely cleared or treeless areas.

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Many colleagues in QDPI&F and QNRW provided support: in planning the project, carrying out field work, data analysis and interpretation, critical insight in reviewing drafts, and advising on statistical and modelling analysis (David Ahrens, John Carter, Neil Flood, Joe Scanlan, Giselle Whish). In particular, the critical comments of David Mayer and Joe Scanlan in the preparation of this document are gratefully appreciated. We also wish to thank John Andrews and Ralph deVoil who were involved in installation of the sites.

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10 Appendices

Available on request from MLA

Appendix 10.1 Botanal regression equations used in field sampling

Appendix 10.2 Complete list of pasture species from all botanal surveys

Appendix 10.3 Intensive grass harvest total standing dry matter (kgha^{-1}) for each site and replicate

Appendix 10.4 Word model of the effects of tree strips with reference to GRASP: preliminary development

Appendix 10.5 Summary of landholder interviews

Appendix 10.6 Evaluation of initial approaches to modelling tree strips

Appendix 10.7 Empirical model of beneficial and competitive effects of tree strips

Appendix 10.8 Temperature and humidity figures

Appendix 10.9 Field survey of individual replicates in December 2006

Appendix 10.10 Simulation modelling

Appendix 10.11 Models of wind direction from relevant meteorological stations

Appendix 10.12 Analysis of pasture standing dry matter measured within the tree strips

Appendix 10.13 Detailed analysis of Mt Lonsdale soil moisture data