Managing the interface of trees and crops – trade-offs in low rainfall zones

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Abstract

This project examined the factors that influence the trade-off between crop yield and recharge control to develop design guidelines for medium to low rainfall agroforestry. Twenty one tree-crop interfaces in the Western Australian wheatbelt and in southern New South Wales were surveyed over two years to determine the relative importance of environmental factors and system characteristics on this trade-off. The factors most strongly correlated with reduced yield loss were water gaining sites (access to perched water tables, run-on water or ground water), aspect and heavier soils. The factors most strongly correlated with the area of cropped land protected against recharge were lighter soils types and trees greater than ten years old.

Media summary

Careful location and orientation of trees used for salinity management can reduce competition with neighbouring crops and improve their water uptake.

Key words:

Alley farming, Intercropping, Integration.

Introduction

In water-limiting environments the successful design for alley cropping depends on managing the interface between the trees and crops to optimise the value of the trees and minimise competition (Lefroy and Stirzaker 1999). The complementarity that exists in a tree-crop system designed for water management is determined from the No-Yield-Zone (NYZ) and the No-Recharge-Zone (NRZ) (Fig. 1) (Stirzaker *et al*. 2002). The NYZ is defined as the lateral distance from the trees over which they effectively reduce yield to zero, while the NRZ is the distance from the trees over which they effectively reduce recharge to zero or to that occurring under native vegetation in the region. Ideally trees in spaced belts would reduce recharge and salinity while allowing crops to be grown profitably between the belts. However, there is a trade-off between yield loss (from tree-crop competition and area of crop displaced by trees) and recharge benefit.

This project set out to identify the relative importance of system characteristics (tree species, tree age, crop type and management) and environmental factors (aspect, soil type, landscape position and hydrology) in determining the trade-off between crop yield losses and recharge control.

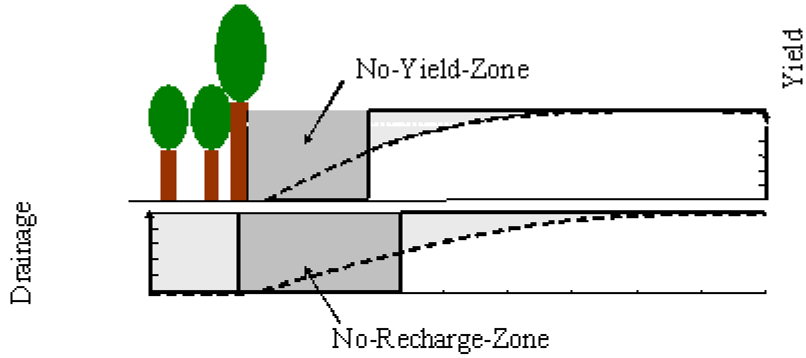

Figure 1. Yield and recharge are both zero at the base of the tree and increase with distance from the tree belt into the sole crop.

Theory

The NYZ is calculated from the transect length and the yield change, which takes into account both yield enhancement and yield decline (Eq. 1). The yield change is calculated from the yield (Y) measured at distances from the tree belt (x) relative to the “open paddock” yield measured at 128 m from the tree base (Y_{128}) (Eq 2) .

$$NYZ = transect\ length \times Yield\ change \quad (1)$$

$$Yield\ change = 1 - \frac{\int_0^{128} Y\, dx}{128 Y_{128}} \quad (2)$$

The NRZ is calculated from the ratio of the leaf area index (LAI) of an edge tree to that of an inner tree or local native vegetation (Eqs. 3 and 4) (Ellis *et al.* 2001). This is used as a surrogate measure of water use and therefore drainage, based on the assumption that the extra growth of the outer trees compared with the smaller inner trees in a belt or the native vegetation in the region, which relies on rainfall alone, is proportional to their access to water from under the adjacent crop (Ellis *et al.* 2001). For Eucalypts, the native LAI can be estimated from rainfall and pan evaporation (Eq. 5) (Ellis *et al.* 2001).

$$NRZ_{outer/inner} = \left(\frac{LAI_{outer}}{LAI_{inner}} \times row\ spacing \right) - \frac{1}{2}\ row\ spacing \quad (3)$$

$$NRZ_{outer/native} = \left(\frac{LAI_{outer}}{LAI_{native}} \times row\ spacing \right) - \frac{1}{2}\ row\ spacing \quad (4)$$

$$LAI_{native} = 2.9 \left(\frac{Annual\ rainfall}{Annual\ evaporation} \right) \quad (5)$$

There are three possible relationships between LAI of the outer trees, inner trees and native trees and soil water management:

1. $LAI_{outer} > LAI_{inner} < LAI_{native}$. The outer trees obtain extra water from under crops and out-compete inner trees which are not reaching the environmental potential of the site.

2. $LAI_{outer} > LAI_{inner} \approx LAI_{native}$. The outer trees experience enhanced growth over inner trees and the growth of inner trees approximates that of native vegetation.

3. $LAI_{outer} > LAI_{inner} > LAI_{native}$. Both inner and outer trees access groundwater or seep water, with the outer trees also accessing water under the crops.

Sites in Category 3 are referred to as water gaining sites, as the trees obtain more water than is available from rainfall (through access to groundwater, seeps or runoff), in addition to accessing water under adjacent crops.

Methods

Twenty one sites in the 300 to 600 mm rainfall zone in the grain producing areas of Western Australia (WA) and New South Wales (NSW) were selected to provide a range of characteristics such as aspect, landscape position, soil types, crop types, tree age and tree species. Biomass and yield were determined from triplicate quadrants (0.5 m ? 0.5 m) cut at 2, 4, 8, 16, 32, 64 and 128 m from the tree base, perpendicular to the treeline. In 2001 crop biomass and yield were monitored at 16 sites in WA and five sites in NSW. Due to crop rotations and drought, only nine sites in WA and two sites in NSW were monitored in 2002. The tree belts were measured for orientation, width of belt, length of belt, diameter at breast height, tree height, canopy widths of trees, distance between trees, distance between rows and leaf area (Table 1). LAI was measured using the Adelaide (module) technique (Andrew et al. 1979) for inner and outer trees.

Results

NYZ and NRZ

The average NYZ extended 11.0 m into the paddock and ranged from a loss of 48.6 m into the crop to an effective gain of 46.8 m of extra land. Yield enhancement near the trees occurred at twelve sites but it was greater than the yield loss at only eight of these sites, producing a positive NYZ (or effective extra land). The predicted $NRZ_{outer/inner}$ ranged from 0.6 to 25 m while the $NRZ_{outer/native}$ ranged from 0.1 to 30.4 m (Table 1). A low $NRZ_{outer/native}$ indicates the trees did not provide much additional recharge control than the area the trees occupy as they are performing much like the native vegetation, surviving on rainfall alone.

a) b) c)

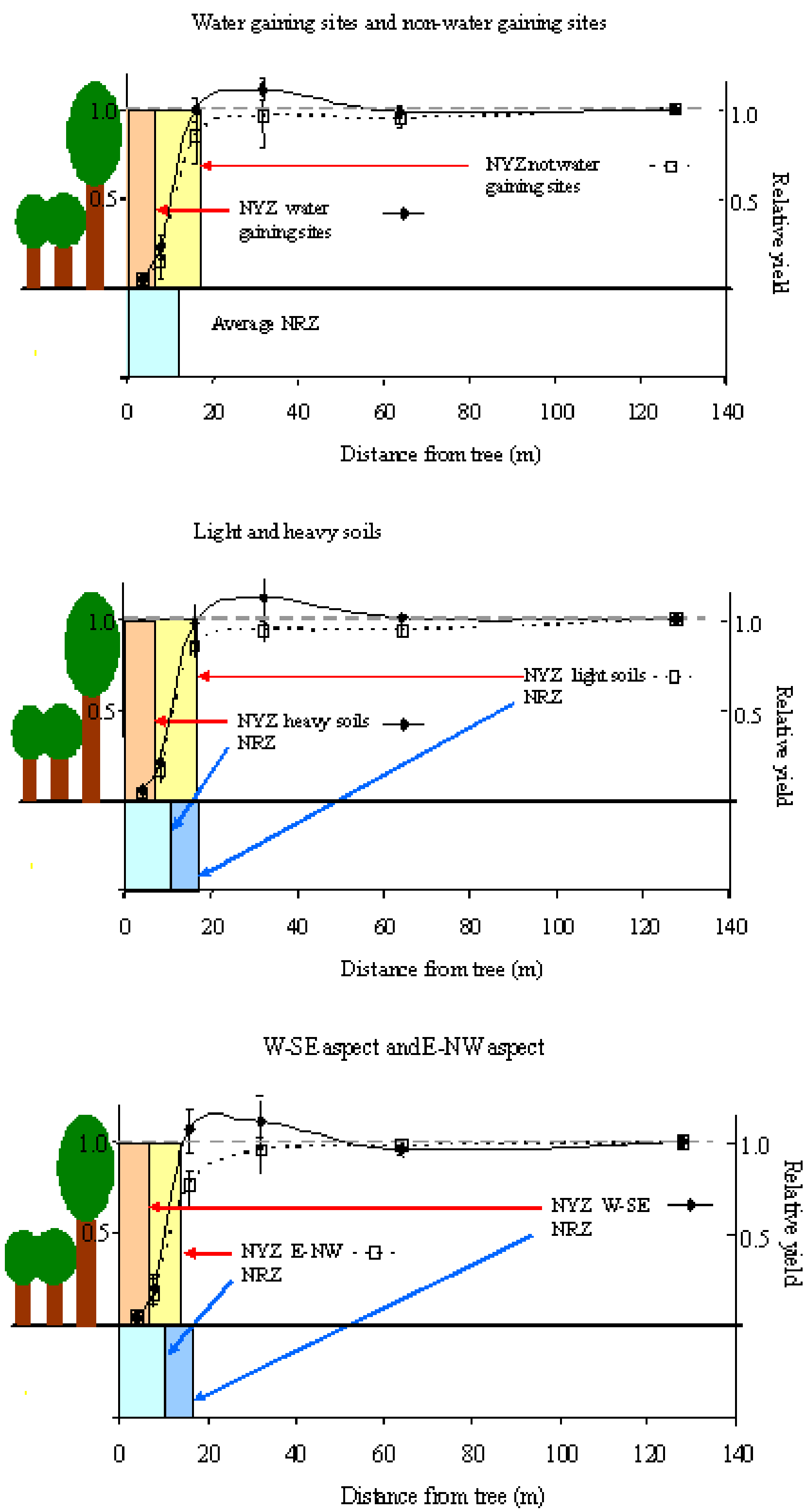

Figure 2. The average NYZ and NRZ for the 32 sites classed as a) water gaining sites and non water gaining sites, b) light soils (sands and loamy sands) and heavy soils (duplex and clays), and c) aspect (crops protected from E-W (east, north-east, north, north-west) and W-SE (west, south-west, south, south-east)).

A comparison of the impact of trees on recharge and yield suggests three possible scenarios:

- Positive trade-off where the impact of trees on crop yield is less than the benefit from drainage reduction, i.e. NYZ<NRZ. This occurred at nine of the 32 sites where alley farming is likely to be an appropriate design strategy.
- Negative trade-off where yield loss is greater than any recharge reduction i.e. NYZ>NRZ. This occurred at 15 of the 32 sites where block plantations are more likely to be the optimal strategy for water management and crop production.
- No trade-off where the tree-crop combination produces a yield enhancement but it may not always guarantee recharge control. This occurred at eight of the 32 sites, however it is likely to have a significant impact on recharge at only three of these sites. Alley farming is the most favourable strategy in a no trade-off situation in terms of crop production, while the impact on recharge management will vary depending on environmental and genotypic factors.

Environmental influences on the NRZ and NYZ

To understand the relative influences of environmental and farming system characteristics on the size of the NYZ and NRZ, the data were separated into classes (Table 1). The site and systems features likely to reduce the size of the NYZ or result in yield enhancement are possibly one or more of the following: 1) water gaining site, 2) crop protection from the west through to the south east (particularly for WA) and 3) heavier soils (Figure 2). However, the net yield gain was seasonally dependant, with a higher NYZ in 2002 and only one site showing gain in both years, reflecting the lower rainfall in 2002 and greater potential for competition between the trees and crops for available water (Ssekabembe *et al.* 1994). A larger NRZ correlated with 1) older trees, 2) lighter soils, 3) low rainfall areas and 4) a southerly to south easterly aspect than other site and system features.

Table 1. Average No-Yield-Zone (NYZ) for sites grouped by region, tree species, crop type, aspect, soil type, landscape position, access to water, tree height (H) and tree age.

	replicates	NYZ (m)	$NRZ_{outer/inner}$ (m)	$NRZ_{outer/native}$ (m)
All	32	11.0 (3.2)	7.3 (1.3)	12.7 (1.6)
WA	25	10.3 (3.8)	5.5 (2.8)	4.3 (2.8)***
NSW	7	13.2 (7.0)	7.7 (1.6)	16.0(1.5)***
Eucalypts	26	11.9 (3.6)	8.4 (1.5)***	12.9 (1.7)
Non-eucalypts	6	6.9 (7.6)	1.6 (3.1)***	16.1 (3.6)
Cereal	23	10.2 (3.9)	na	na
Non-cereal	9	13.0 (6.8)	na	na
Aspect – E, NE, N, NW	16	14.8 (4.6)*	5.9 (1.8)	10.1 (2.1)***

Aspect – W, SW, S, SE	16	7.0 (4.7)*	8.9 (2.1)	16.8 (2.1)***
Light soils	14	16.3 (4.8)**	10.8 (1.6)***	17.3 (2.2)***
Heavy soils	18	6.8 (4.2)**	5.1 (2.2)***	10.5 (2.1)***
High in landscape	18	11.3 (5.0)	5.8 (1.8)	11.4 (2.4)
Low in landscape	14	10.7 (5.4)	7.9 (1.7)	14.5 (2.2)
Water gaining sites[a]	18	6.7 (4.4)**	na	na
Non water gaining sites	11	17.2 (5.7)**	na	na
Short trees <8 m	21	8.6 (4.1)	8.2 (1.7)	14.5 (1.9)
Tall trees >8 m	11	15.4 (5.5)	5.0 (2.4)	11.6 (2.7)
Young trees <10 years	10	10.0 (4.1)	3.5 (2.4)***	12.3 (2.9)
Old trees >10 years	22	11.4 (4.1)	9.1 (1.6)***	13.8 (2.0)
Rainfall >400 mm	18	14.1 (4.1)	4.6 (1.8)***	na
Rainfall <400 mm	14	6.9 (4.9)	10.1 (1.9)***	na

$^{***}P<0.1$, $^{**}P<0.2$, $^{*}P<0.25$, [a] The water gaining sites were determined from the LAI_{outer}, LAI_{inner} and the LAI_{native} and does not include 3 sites as they only had two rows of trees (i.e. no inner row). Light soils = sand and sandy clays, Heavy soils = heavy duplex clays.

Conclusions

Seasonal conditions had a strong influence on the complementarity between water management and yield, with some sites being in positive trade-off in one year and negative trade-off in the other. As agroforestry systems are long lived and therefore relatively inflexible their adoption is risky in water limited environment with high climate variability. This research suggests this risk could be reduced if attention is paid to the following factors that were most strongly correlated with reduced competition with crops and high recharge management: 1) water gaining sites (access to perched water tables or run-on water and ground water), 2) protection of crops from the west, south west, south or south east, 3) tree age (>10 years) and 4) lower rainfall (<400 mm). Further work is required to produce a probabilistic prediction of trade-off over time.

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