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Research paper

Water use, root activity and deep drainage within a perennial legume-grass pasture: A case study in southern inland Queensland, Australia

Uso de agua, actividad radicular y drenaje profundo en una pastura leguminosa-gramínea perenne: Un estudio de caso en el sur de Queensland, Australia

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Abstract

Water use and depth of water extraction of leucaena (*Leucaena leucocephala*) and Rhodes grass (*Chloris gayana*) pasture, irrigated with desalinated coal seam water (a by-product of the coal seam gas industry), were monitored to provide background information on root activity, spatial and temporal water use and deep drainage over a 757-day period from August 2011 to August 2013. Methodology comprised measurement of soil water from surface to 4 m depth using 8 EnviroSCAN probes connected to dataloggers positioned within leucaena twin rows and within the Rhodes grass inter-row. Just over 581,000 individual moisture measurements were collated and are reported here. Water extraction (and by inference root activity) of leucaena and Rhodes grass showed marked seasonal fluctuation with deepest and highest water extraction occurring during the first growing season; water extraction was greatly diminished during the following drier and cooler seasons due to the negative influences of lower soil moisture contents, lower temperatures and increased defoliation on pasture growth. The highest values of deep drainage below 4 m depth occurred when high rainfall events corresponded with high soil water storage in the entire profile (0–4 m depth). Given that water usage by both leucaena and Rhodes grass was greatest in the upper layers of soil (<1.5 m), future research should focus on how the level of competitive interaction might be managed by choice of row spacing and frequency of irrigation. Further studies are needed, including: (a) physical sampling to determine the depth of active roots; (b) how defoliation affects rooting behaviors and water use of leucaena; and (c) modelling of the water and salt balances of leucaena and grass inter-row systems using data from this study, with various levels of irrigation, to investigate the risks of deep drainage over an extended climate sequence.

Keywords: Active rooting depth, agroforestry, *Chloris gayana*, *Leucaena leucocephala*, water extraction.

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Resumen

En el presente estudio se caracterizó el uso del agua y la profundidad de extracción de agua en una pastura compuesta por leucaena (*Leucaena leucocephala*) y pasto Rhodes (*Chloris gayana)*, irrigada con agua desalinizada proveniente de vetas de carbón [un subproducto de la industria del gas de vetas de carbón (*coal seam gas, CSG*)], para generar información sobre la actividad radicular, el uso de agua en el espacio y tiempo, y el drenaje profundo durante un período de 757 días (agosto de 2011 hasta agosto de 2013). La metodología consistió en mediciones de la humedad de suelo desde la superficie hasta 4 m de profundidad utilizando 8 sondas EnviroSCAN conectadas a dataloggers situados dentro de las hileras dobles de leucaena y las franjas del pasto entre las hileras de leucaena. Se presenta la compilación de algo más de 581.000 mediciones individuales de humedad que fueron ejecutadas. La extracción de agua (y, por inferencia, la actividad radicular) de leucaena y el pasto Rhodes mostraron una marcada fluctuación estacional, con mayor y más profunda extracción de agua durante el primer ciclo de crecimiento. La extracción de agua se redujo en gran medida durante las subsiguientes temporadas más frías y más secas, debido a los efectos negativos de la humedad de suelo más baja, las temperaturas más bajas y el incremento de la defoliación sobre el crecimiento del pasto. Los valores más altos de drenaje a una profundidad mayor de 4 m se registraron cuando eventos de alta precipitación correspondían con un alto almacenamiento de agua a lo largo de todo el perfil (0–4 m de profundidad). Se necesitan estudios adicionales, incluyendo: (a) muestreos para determinar las profundidades hasta las cuales se encuentran raíces activas; (b) cómo la defoliación afecta el sistema radicular y el uso de agua de leucaena; y (c), mediante el uso de los datos de este estudio, modelando los balances de agua y de sales en sistemas silvopastoriles con hileras de leucaena y franjas de pasto, con varios niveles de riego, para investigar los riesgos de drenaje profundo durante una secuencia climática extendida.

Palabras clave: Agroforestería, *Chloris gayana,* extracción de agua, *Leucaena leucocephala,* profundidad radicular.

Introduction

Intensive production systems such as *Leucaena leucocephala* (leucaena)-grass pastures are the key to enhancing profitable cattle production in northern Australia. With an area greater than 200,000 ha in Queensland, leucaena-grass pastures have been shown to be productive, profitable and sustainable (Shelton and Dalzell 2007). Furthermore, irrigation of leucaena can increase beef production by 3–6 times compared with dryland plantings (Shelton and Dalzell 2007).

Over the past decade, coal seam gas (CSG) exploration in southern Queensland has expanded rapidly, generating a large amount of water as a by-product of the gas extraction process, which must be put to beneficial use. Irrigated systems, capable of using large volumes of water with minimal risk impact on natural aquifers, are needed.

The decision by CSG companies to irrigate leucaena combined with Rhodes grass (*Chloris gayana*) was based on the hypothesis that the roots of trees and grass occupy different soil strata when growing in association (Schroth 1999) and are capable of maximizing water use in the profile and minimizing deep drainage. In the case of leucaena-grass pasture systems, there is limited information concerning root distribution and water uptake. According to Poole (2003) and Radrizzani (2009), approximately 60% of root biomass of a leucaena-grass pasture was concentrated in the top 0.4 m of the soil profile, with root abundance decreasing rapidly at greater depths, although some roots reached a depth of 6 m under 5–10-year-old leucaena. However, other studies have reported maximum root depth at only 2.8 m in 28-month-old leucaena (Dhyani et al. 1990) and at 2.6 m in 38-year-old leucaena in alley cropping with pasture (Radrizzani 2009) in soils with physical restrictions. Both of these studies reported a restrictive rock layer at these depths, which prevented leucaena from exploring deeper into the regolith.

Technologies for soil water monitoring have advanced over the past decade. EnviroSCAN (Sentek Pty. Ltd., Stepney, South Australia) capacitance systems are used in Australia and other countries to accurately monitor soil water content for irrigation management by measuring the electrical constant of the soil (Jabro et al. 2005). Precise measurements of soil water are critical for a better understanding of water use by crops and pastures and for irrigation scheduling. For instance, water management can be used to prevent or promote flushing of excess soil salt via drainage below the rooting zone.

Accordingly, as a prelude to a formal program of research, this study was designed to monitor soil water extraction under a leucaena-Rhodes grass pasture using EnviroSCAN to provide background information on: (a) the maximum depth of water extraction (and by inference root activity); (b) the amount and pattern of water extraction; and (c) the likelihood of deep drainage below 4 m depth.

Materials and Methods

Site details

Moisture usage was monitored at Santos' Fairview gas field north-east of Injune, Queensland (25°44'40" S, 149°3'19" E), where 234 ha of *Leucaena leucocephala* ssp. *glabrat*a and *Chloris gayana* was being irrigated using desalinated CSG water under 4 centre-pivot irrigation systems. The leucaena (cvv. Wondergraze and Tarramba) was sown in November 2009 in twin rows (1 m apart) with 8 m spacing between the centers of the paired hedgerows. Oats, ryegrass and Rhodes grass (cv. Finecut) were sown between the leucaena twin rows in March-April of 2010 but from 2011 onwards, the alley-ways between the leucaena twin rows were dominated by Rhodes grass. The soil types were Black and Red Vertosols (Isbell 1996), and at all locations the soil profile was >2 m depth to the C horizon and 3-4 m to regolith (substrate).

The subtropical climate has an annual rainfall of 628 mm and average maximum and minimum temperatures of 33.6 and 19.6 °C, respectively, in the hottest month (January) and 20.1 and 3.2 °C in the coolest month (July) (Bureau of Meteorology 2014). An automatic weather station recorded daily rainfall, maximum and minimum temperatures, wind speed, total radiation and potential evapotranspiration (PET) using the Penman-Monteith equation (Allen et al. 1996).

Soil water measurements

Volumetric soil water content was monitored at 4 sites using 8 EnviroSCAN probes connected to dataloggers (RT6 logger, Sentek Pty. Ltd.) with a sampling interval of 15 minutes. Each EnviroSCAN probe had 7 capacitance sensors located at 0.1, 0.3, 0.6, 1.2, 2, 3 and 4 m below ground level and data were collected over 757 days from August 2011 to August 2013. Four probes (1–4) were positioned within the leucaena twin rows and 4 probes (5–8) within the Rhodes grass inter-row sward at 2 sites, 2 and 4 m from the center of the leucaena twin rows. Field capacity point (FC) and wilting point (PWP) were estimated using IrriMAX 9.1.1 software tools (Version 9.1.1, Sentek Pty. Ltd.). Total plant-available water (PAW) was calculated from the difference between FC and PWP (Figure 1).

The sensors were installed following the recommendation of Sentek Pty. Ltd., and an in-situ calibration equation was developed for each soil (SENTEK 2001).

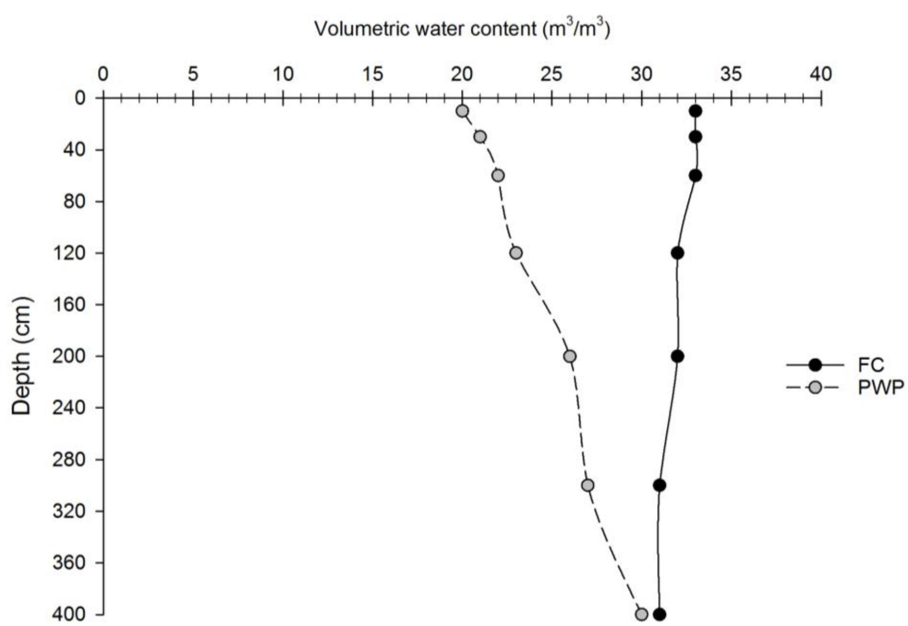

Figure1: Profile of soil water content used for the study. FC = field capacity; PWP = permanent wilting point.

Depth of water extraction

Depth of water extraction, assumed to be indicative of the maximum depth at which roots were actively taking up water, was estimated using the IrriMAX 9.1.1 software tools by measuring the depletion of water in the soil profile during days when no precipitation was recorded. Using the graphing tools of IrriMAX 9.1.1, it was possible to observe the activity of roots as defined by daily extraction patterns of >0.1 mm per day. Using this method, it was possible to generate a large database reflecting the extent and depth of water extraction (root activity) per month at each probe.

Water uptake and deep drainage

Decreases in soil water content could be due to evapotranspiration, plant water uptake (WU), runoff (R) or drainage (D). The EnviroSCAN data were used to calculate WU and D for the top 4 m of soil profile from 1 August 2011 to 27 August 2013 at 15-minute intervals. Any change in soil water content between 18:00 and 06:00 h was assumed to be drainage, as evaporation and plant uptake were assumed to be negligible during the night (Ward et al. 2014). Runoff was minimized by the high ground cover of the pasture but could not be estimated by the EnviroSCAN probes.

Daily water use (mm/d) at different depths (0.1, 0.3, 0.6, 1.2, 2, 3 and 4 m) was calculated using IrriMAX 9.1.1 software. Daily WU for the whole profile was obtained by interpolation between sensors.

Deep drainage (mm) below 4 m depth was estimated for all probes.

Statistical analyses

A total of 72,635 data points was logged for each probe, totalling 581,080 data points during the 757 days of study. Basic statistics were used to compare depth of water extraction, soil water extraction and deep drainage below 4 m depth data and averages and standard errors were calculated for these parameters plus potential evapotranspiration. Within leucaena twin rows, the averages for probes 1–4 (n=4) were used; within the grass inter-row, the data for probes located 2 and 4 m from leucaena twin rows were pooled (n=4). Data were pooled for the soil types as there were no differences in water use.

Results

Site information

A total of 552 mm rain was recorded during the first growing season (October 2011–May 2012), and only 338 mm during the second growing season (October 2012–May 2013) (Figure 2a). Rainfalls during the cool dry seasons (June–September) were 55, 149 and 7 mm for 2011, 2012 and 2013, respectively. (Note: There was an unseasonably high rainfall event of 122 mm during the month of June 2012). The average monthly maximum and minimum temperatures for the growing seasons were 30.1 and 15.6 °C, respectively; values for the cool dry seasons were 21.3 and 5.4 °C. The average values for potential evapotranspiration (PET) were 4.5 and 5.3 mm/d for the first and second growing seasons, respectively. PET for the cool seasons was similar in 2011, 2012 and 2013 with an average of 2.9 mm/d.

Supplementary irrigation was applied from the beginning of the study period but ceased due to lack of available water in April 2012 for probes 1, 3, 4, 5 and 6 and in July 2012 for probes 2, 7 and 8, when 155 mm had been applied (Figure 2a). Grazing commenced in late 2010, 12 months after planting. Initially the pastures were rotationally grazed and cattle were moved to allow at least 50 days recovery. In February 2012, all leucaena was pruned to a height of 0.5 m above the ground to control excessive height and thereafter was continuously grazed.

Soil water content and plant available water

Over the 2 years of the study, the average stored soil water (0–4 m depth) within leucaena twin rows and within grass inter-rows varied from 1,244±7 to 940±41 mm. The average values for field capacity and wilting point were 1,168 and 937 mm, respectively. Thus, regardless of location, relative plant available water (PAW) varied from 100% in August 2011 to 1% in August 2013 (Figure 2b). The unusually high rainfall event in June 2012 refilled the soil profile; however, thereafter PAW decreased due to lack of rainfall and irrigation.

Depth of water extraction

Overall, depth of water extraction was deeper in the growing seasons than in cool dry seasons, regardless of probe locations (Figures 3a and 3b). In the first growing season, water extraction within leucaena twin rows (leucaena-dominant) extended to an average depth of 2.2±0.15 m (maximum depth of water extraction was 4 m) (Figure 3a). During the second growing season, depth of water extraction reached 1.9±0.20 m (maximum rooting depth was 4 m). Average depths of water extraction within the grass inter-row (Rhodes grass-dominant) during the first and second growing seasons were 1.8±0.15 and 1.2±0.9 m, respectively, while maximum depth of water extraction within the grass inter-row was 3.5 m (Figure 3b). Depth of water extraction was less than 0.9 m for both pasture types in the cool dry seasons (Figure 3b).

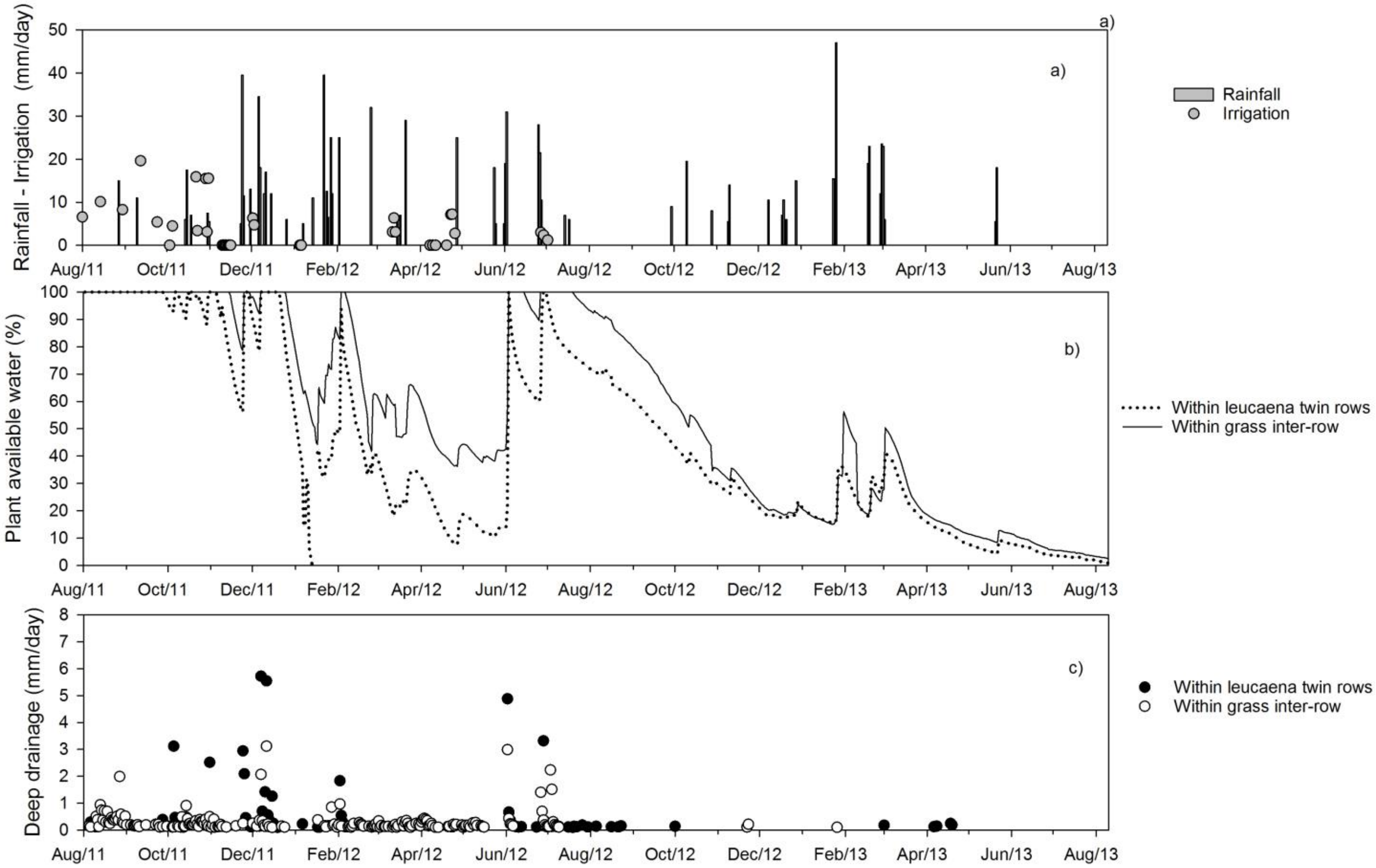

Figure 2. a) Rainfall and irrigation events; b) percentage of plant available water within leucaena twin rows and within the grass inter-row; and c) average daily deep drainage >0.1 mm/d within the leucaena twin rows and within grass inter-row during the period of study.

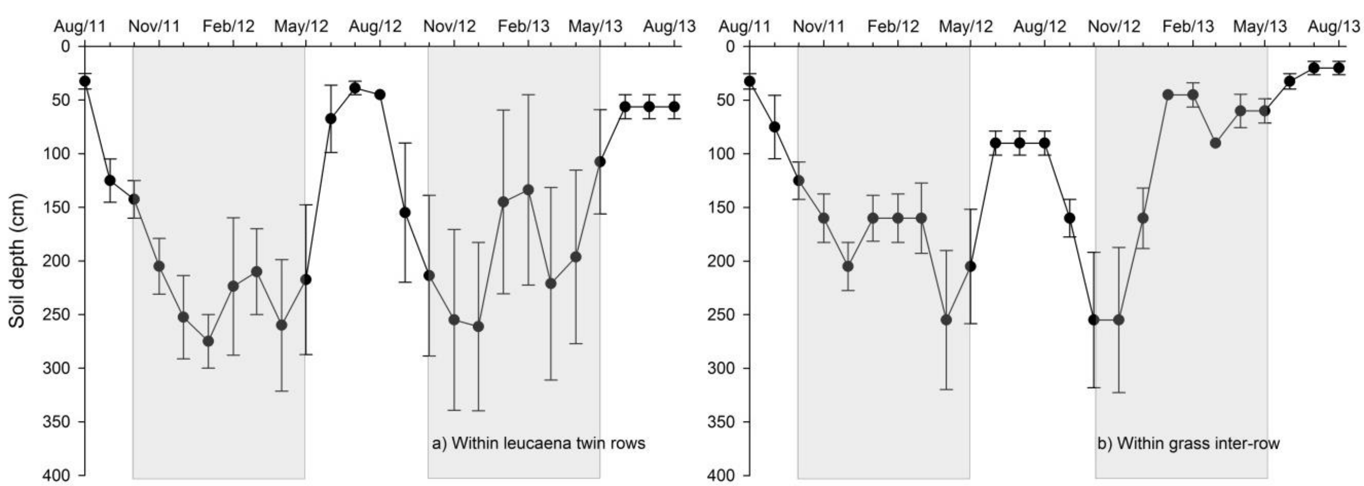

Figure 3. Monthly maximum depth of water extraction detected with IrriMax 9.1.1 software: a) within leucaena twin rows; and b) within the grass inter-row. Growing seasons are shown in light grey and standard error by bars (n=4).

Temporal and spatial patterns of water extraction

In general, greatest water extraction occurred in the first wet season. In all seasons, water extraction was highest in surface soil zones, and reduced with depth (Figure 4).

During the first growing season, total WU within leucaena twin rows (probes 1–4) was 675±181 mm; however, average WU was higher for probes 1 and 2 at 916±280 mm. An average (probes 1–4) of 77% of water was extracted from surface soil to 1.5 m depth, increasing to 99% for 1.5–3 m depth (Figure 4a; Table 1). During the second growing season, WU was lower at 303±61 mm, of which 75% was extracted from surface to 1.5 m depth, increasing to 94% for 1.5–3 m depth. During the cool dry seasons, the total WU within leucaena twin rows during 2012 was 81±16 mm, reducing to 40±8 mm in 2013, of which 100% was extracted from surface to 1.5 m depth (Table 1).

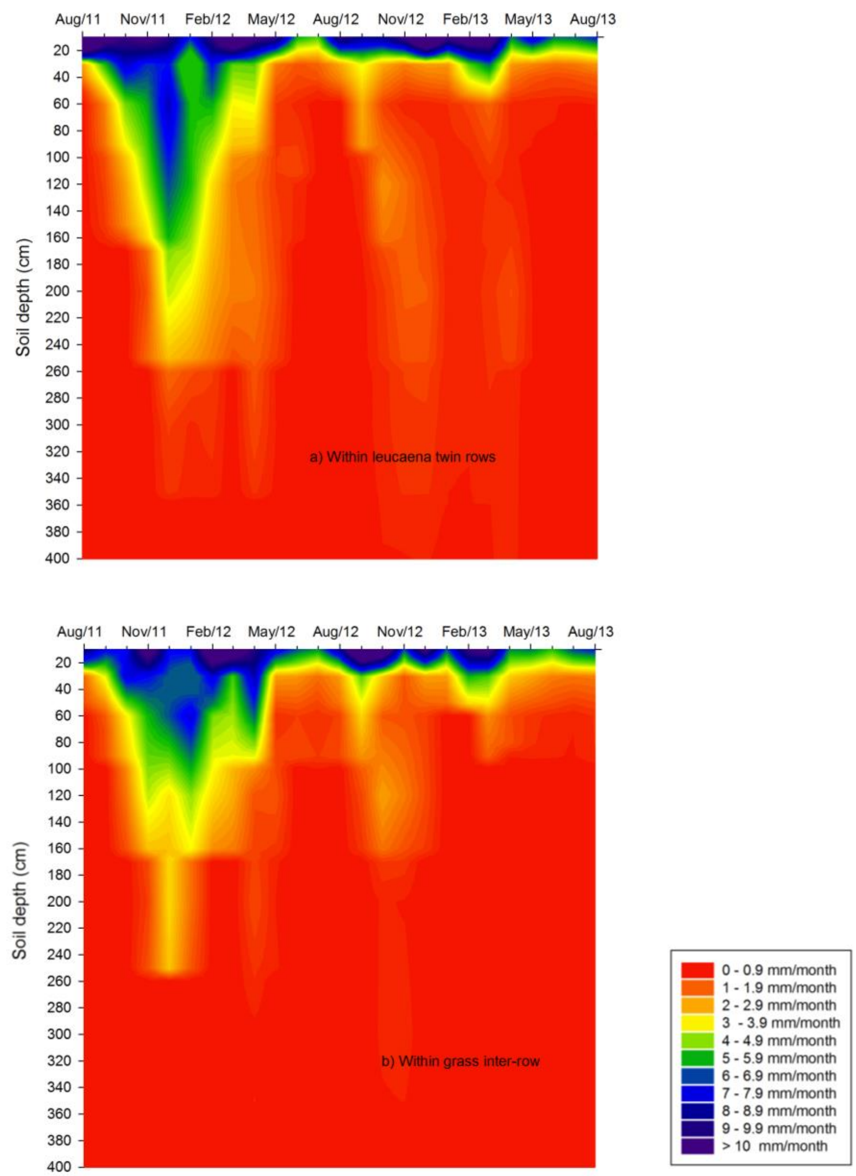

Figure 4. Patterns of average water extraction: a) within leucaena twin rows; and b) within the grass inter-row per 0.1 m soil layer from August 2011 to August 2013. The monthly amount of water extracted per layer is expressed by different colors (mm/month).

Table 1. Accumulated total water extraction per layer and total deep drainage below 4 m depth within leucaena twin rows and within the grass inter-row during the growing and cool dry seasons of 2012 and 2013. Standard errors are presented in italics.

Depth (m)	Average total water extraction per season (mm)											
	Within leucaena twin rows (probes 1–4) (n=4)				Within leucaena twin rows (probes 1–2) (n=2)				Between leucaena twin rows (probes 5–8) (n=4)			
	1st GS (304 days)	1st CDS (122 days)	2nd GS (243 days)	2nd CDS (88 days)	1st GS (304 days)	1st CDS (122 days)	2nd GS (243 days)	2nd CDS (88 days)	1st GS (304 days)	1st CDS (122 days)	2nd GS (243 days)	2nd CDS (88 days)
0–0.5	256 ±*58*	62 ±*16*	181 ±*25*	38 ±*8*	339 ±*80*	87 ±*19*	223 ±*14*	42 ±*18*	322 ±*66*	113 ±*18*	196 ±*8*	65 ±*19*
0.5–1	152 ±*34*	12 ±*3*	21 ±*7*	2 ±*2*	191 ±*62*	10 ±*6*	21 ±*2*	0	163 ±*37*	28 ±*4*	35 ±*35*	0
1–1.5	111 ±*29*	4 ±*3*	25 ±*9*	0	152 ±*25*	1 ±*1*	31 ±*6*	0	131 ±*18*	7 ±*3*	23 ±*23*	0
1.5–2	75 ±*26*	1 ±*1*	23 ±*10*	0	111 ±*37*	0	25 ±*11*	0	40 ±*8*	1 ±*1*	5 ±*2*	0
2–2.5	56 ±*22*	0	21 ±*10*	0	83 ±*37*	0	20 ±*11*	0	16 ±*9*	0	1 ±*1*	0
2.5–3	15 ±*12*	0	13 ±*9*	0	25 ±*15*	0	8 ±*4*	0	1 ±*1*	0	1 ±*1*	0
3–3.5	10 ±*7*	0	11 ±*8*	0	15 ±*7*	0	6 ±*3*	0	0	0	1 ±*1*	0
3.5–4	0	0	8 ±*7*	0	0	0	0	0	0	0	0	0
Total	675 ±*181*	81 ±*16*	303 ±*61*	40 ±*8*	916 ±*280*	97 ±*30*	334 ±*99*	42 ±*14*	673 ±*107*	149 ±*21*	262 ±*23*	65 ±*19*
DD (mm)	32 ±*9.4*	11 ±*4*	5 ±*1.4*	2 ±*1*	43 ±*7.6*	17 ±*5.0*	8 ±*2.3*	2 ±*0.3*	39 ±*9.4*	16 ±*2.5*	7 ±*1.6*	2 ±*0.4*
R (mm)	552	149	338	7	552	149	338	7	552	149	338	7
IR (mm)	126	26	0	0	103	26	0	0	103	26	0	0
Δ SWC (mm)	248	-62	74	15	278	-109	130	22	248	-45	112	25

GS: growing season; CDS: cool dry season; DD: depth drainage; R: rainfall; IR: irrigation; and Δ SWC: change in soil water content.

During the first growing season, WU within the grass inter-row of probes 5–8 averaged 673±107 mm (Figure 4b; Table 1). However, the spatial patterns of water uptake were different from those within leucaena rows, with 92% of water extracted from surface to 1.5 m depth. During the second growing season, total water extracted was greatly reduced to 262±23 mm, with 89±5% extracted to 1 m depth. During the first cool dry season, average total water uptake was 149±21 mm (Table 1), with 97% extracted from surface to 1.5 m depth. During the second cool dry season, total water uptake was lower at 65±19 mm, with 100% of water being extracted from surface to 0.5 m depth (Table 1).

Deep drainage below 4 m depth

Deep drainage below 4 m for the study period was 50±12.5 and 64±15.4 mm for the leucaena and grass inter-row, respectively. This is 4.1 and 5.4% of total rainfall plus irrigation.

It was greatest when significant rainfall events occurred when moisture content of soil profile was near FC (Figures 2a and 2b; Table 1). Thus highest deep drainage occurred when rainfall events refilled the soil profile to more than 1,200 mm, i.e. ≥100% PAW (Figures 2a and 2c). Deep drainage within leucaena twin rows was 31.5±9.4 mm during the first growing season, but lower at 4.5±1.4 mm during the second growing season. In the first cool dry season of 2012, deep drainage was 11.1±4 and 1.8±1 mm during the cool dry season of 2013.

Within the grass inter-row during the first and second growing seasons, deep drainage volumes were 38.7±9.4 and 6.6±1.6 mm, respectively. These volumes were similar to the 43±7.6 and 8.3±2.3 mm of deep drainage registered for probes 1 and 2 located within leucaena twin rows. By comparison deep drainage volumes within the grass inter-rows during the cool dry seasons were 16±2.5 and 2.4±0.4 mm for 2012 and 2013, respectively.

Discussion

The motivation for this study was based on the requirement that ground water extractions, as part of the CSG process, must be used for beneficial purposes, e.g. irrigation of agricultural crops and pastures. As CSG water varies in availability from limited to excess volumes, the potential outcomes of such variable irrigation scheduling need to be better understood.

The objective of this study was to monitor and describe the water extraction (and by inference apparent root activity) and deep drainage of an irrigated leucaena-grass pasture grown on Vertosols. The methodology comprised 2 years of detailed monitoring of spatial and temporal patterns of water extraction, and hence root activity, and deep drainage below 4 m depth. Data showed that all parameters varied depending on rainfall events, season and management of the leucaena-grass pastures.

Root activity and water extraction

Depths of water extraction and water uptake patterns, shown so dramatically in Figure 4, are of particular interest in agroforestry systems as trees and grasses are considered to occupy different soil strata when grown in association (Schroth 1999). In this survey, water extraction was used as a proxy for depth of rooting activity. Maximum depth of water extraction and water use (WU) were modestly greater within leucaena twin rows (leucaena-dominant) than within the grass inter-row (Rhodes grass-dominant). When growing at maximum capacity in the first growing season, water extraction within leucaena twin rows extended to an average depth of 2.2±0.15 m with a maximum depth of 4 m. By contrast, mean depth of water extraction within the grass inter-row was 1.8±0.15 m with a maximum depth detected of 3.5 m. It is unlikely that roots of grass reached 3.5 m depth, and it is possible that lateral roots of leucaena were exploiting soil moisture under the grass inter-row. Further studies are needed, including physical sampling of plant roots, to determine the origin of active roots.

The percentage of total WU within leucaena twin rows below 1.5 m depth was 25% (leucaena-dominant) compared with just 10% between rows (Rhodes grass-dominant). This suggested that there was only a small degree of complementarity in water use between the trees and grass, with leucaena accessing water deeper in the soil profile. Various authors mention that, in successful agroforestry systems, trees can access water resources that the crop or grass would not otherwise access (Cannell et al.1996; Schroth 1999; Fernandez et al. 2008). This assertion was not strongly supported in this study.

These results confirm those reported by Poole (2003), who found that maximum rooting depth for another tropical grass (buffel grass, *Cenchrus ciliaris*) was 1.7 m in Grey Vertosols in central Queensland, Australia. However, the depth of water extraction and by inference active rooting depth of leucaena observed in this study was much shallower than that reported by Poole (2003), who found physical evidence of roots of 5–10-year-old *L. leucocephala* to 5.9 m depth. Rooting depths similar to ours have been reported at 2.8 m in 28-month-old leucaena (Dhyani et al. 1990), at 2.6 m in 38-year-old leucaena in alley cropping with pasture (Radrizzani 2009) and at 2 m in an alley cropping system with maize (Rao et al. 1993).

Active water extraction by leucaena was shallower during the second growing season due to the combined effects of lower rainfall, absence of irrigation and severe defoliation by pruning and grazing. This was unexpected as leucaena has a reputation for continuing to grow during prolonged dry periods, when upper layers of the soil profile are dry (i.e. soil water content <PWP); this attribute is often cited as one of its major production advantages (Shelton and Dalzell 2007). We postulate that the more severe defoliation experienced in the second growing season may have contributed to the lower WU of leucaena during this time. The effects of continuous heavy grazing were also severe on Rhodes grass, as depth of water extraction reduced from 1.5 m to 0.5 m. During the cool dry seasons, the shallow depths of water extraction by both species (0.66±0.18 m) could be attributed to lower temperatures, which would have limited plant growth (Cooksley et al. 1988; Moore et al. 2006).

Water uptake patterns

Water uptake was greatest in the upper soil profile and decreased with depth. This pattern reinforces the findings of Callow (2011), who reported that the capacity of warm season forages to extract soil water generally decreased with depth.

Season had a strong influence on total water extraction, which was highest in the first growing season due to high evapotranspiration demands associated with rapid growth of the pasture and adequate soil water content leading to deeper root exploration by both leucaena and Rhodes grass.

The amount of water extracted during the cool dry seasons was much lower than during the growing seasons as low soil water levels coupled with lower temperatures, as well as defoliation, would have limited plant growth. The influence of defoliation on WU requires further study. Overall, the amounts of water extracted were lower than those reported by Narain et al. (1998) at a location receiving an average of 1,523 mm of rainfall. In a 4-year study of water use under different land uses, which included a leucaena monoculture and a leucaena-grass system, they reported average WUs of 1,528 and 1,397 mm/yr, respectively. They found similar seasonal differences in water extraction between growing and cool dry seasons, with water extraction limited by low available soil moisture and reduced plant growth during winter.

Water use of leucaena versus grass

There was some evidence that leucaena extracted more water than grass alone as its greater depth of rooting made a modest difference in water uptake. Water extracted within the grass inter-row (Rhodes grass-dominant) was 25% lower than that extracted within leucaena twin rows. According to Schroth (1999), while depth of root exploration is important, it is necessary also to consider root distribution and root activity within the soil profile.

Deep drainage below 4 m depth

Although the potential advantages of leucaena-grass systems in controlling deep drainage is hypothesized (Shelton and Dalzell 2007), there are few data on the amount of deep drainage that occurs in leucaena-grass pastures. However, there are considerable data on deep drainage in pasture and native vegetation (Owens et al. 2004; Silburn et al. 2009; Tolmie et al. 2011). In this study, daily deep drainage below 4 m differed between growing seasons and cool dry seasons. Deep drainage was greatest when significant rainfall events or frequent irrigation occurred at times when the soil moisture profile was near field capacity. Thus higher daily deep drainage occurred during the first growing season and the cool dry season of 2012 following an unseasonal rainfall event. During the late phase of the study, when rainfall and corresponding soil moisture values were much lower, average drainage was low. There was no major difference between deep drainage within leucaena twin rows and within the grass inter-row.

Poole (2003) modelled the probability of deep drainage under leucaena-buffel grass pastures, buffel grass only and annual summer grain (sorghum) cropping over a 100-year period and also found that higher rates of deep drainage were related to higher rainfall events. The model predicted that there would be less deep drainage under leucaena-grass pastures than under buffel grass pastures and grain sorghum annual cropping. In soils without limitation, the probability of annual deep drainage of 50 mm (over a 100-year period) was 85% for annual sorghum cropping, 60% for buffel grass pastures and 20% for leucaena-grass pastures. Robinson et al. (2010), using simulation modelling for Goondoola Basin in a semi-arid region of Queensland, found that deep drainage was strongly related to soil type and vegetation; clearing native vegetation and introducing crops and pastures increased deep drainage. Pastures with deeper roots (2.4 m depth), such as leucaena-grass pasture, growing on 6 different soil types had 25 mm less of deep drainage than wheat cropping.

The study period had below average to average rainfall and greater deep drainage would be expected in wetter years and with greater irrigation, although growth and water use may also be greater. Modelling of the water and salt balances of leucaena and grass inter-row systems using data from this study, with various levels of irrigation, is recommended to investigate the risks of deep drainage over an extended climate sequence.

Conclusions

EnviroScan sensors were a useful tool for characterizing spatial and temporal patterns of water extraction, and by inference root activity of leucaena-Rhodes pasture. A marked seasonal water extraction was observed which was greater during growing seasons and lower in cool dry seasons. Both leucaena and Rhodes grass extracted a greater amount of water in the upper layers, suggesting high levels of competition for water resources between species. Low rainfall, defoliation and low temperatures negatively affected depth of water extraction and therefore reduced total water extraction. There was some evidence that leucaena roots were active slightly deeper in the soil profile than roots of Rhodes grass.

The highest values of deep drainage below 4 m occurred when rainfall events coincided with soil moisture near to 100% PAW. Therefore, irrigation should be avoided at this time. Deep drainage below 4 m within leucaena twin rows differed little from that within the grass inter-rows.

Given that water usage by both leucaena and Rhodes grass was greatest in the upper layers of soil (<1.5 m), future research should focus on how the level of competitive interaction might be managed by choice of row spacing and frequency of irrigation. Also, additional studies are needed, including: (a) physical sampling to determine the depth and distribution of active roots; and (b) how defoliation affects rooting behavior and water use of leucaena. Modelling of the water and salt balances of leucaena and grass inter-row systems using data from this study, with various levels of irrigation, is recommended to investigate the risks and advantages of deep drainage to manage soil salt profiles.

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