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Managing Tree- pasture Competition by Using Perennial Forage Species

**A report for the RIRDC/Land & Water
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Joint Venture Agroforestry Program**

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Foreword

Agroforestry involves integrating trees with agriculture as part of whole-farm management, with the decisions made by the farmer or landholder about their farm. Adoption of agroforestry is currently constrained by uncertainties about the economics of the tree component and the perceived negative impacts of trees on agricultural enterprises. There can be considerable losses in the productivity of annual crops and pastures alongside trees in alley and windbreak systems. But recent experimental evidence suggests that some perennial pastures are less affected by tree competition. Also, compared to annual-pasture-based systems, perennial pastures offer a number of potential benefits – importantly, they can increase livestock production and reduce soil erosion and groundwater recharge. This has potential benefits for the farming community.

Agroforestry systems where pasture production is not reduced in the competition zone will be more attractive to farmers seeking to maintain or increase income from their agricultural enterprises, or those who are adopting these systems for the first time. The challenge to developing viable agroforestry systems incorporating perennial pastures lies in identifying and proving a range of perennial pasture species tolerant of competition with trees and suited to various soils and rainfall zones.

The aims of this one-year scoping study were to identify perennial forage species that compete successfully with trees for water, nutrients and light in the medium to low rainfall zone in south-west Western Australia, and to assess what effect perennial pastures have on tree root morphology and water-use compared to annual pastures.

The study identified a range of perennial pasture species which are competitive with trees for pasture production. These results are promising for improved production and integration of trees and pasture, as well as achieving water interception and catchment management benefits.

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This report is an addition to RIRDC's diverse range of over 1600 research publications. It forms part of our Agroforestry and Farm Forestry R&D program, which aims to integrate sustainable and productive agroforestry within Australian farming systems. The JVAP, under this program, is managed by RIRDC.

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Executive Summary

What the report is about

This report presents a preliminary study to identify perennial forage species that compete successfully with trees in agroforestry systems in the medium to low rainfall zone in south-west Western Australia. Yields from annual and perennial pastures adjacent to tree belts are given, and the report recommends several perennial pasture species for use in agroforestry systems.

Who is the report targeted at?

The report is for use by farmers, agricultural advisors, farm forestry extension officers and researchers. The results of this study should also inform agricultural policy and research and development (R&D) funding agencies.

Background

Research has shown that there can be considerable losses in the productivity of annual crops and pastures alongside trees in alley and windbreak systems. While these losses can be managed in some situations they remain a disincentive to producers considering adopting agroforestry systems. However, work in Western Australia has shown that kikuyu pasture can be grown in the root zone of trees with no reduction in pasture productivity. This opens up the possibility of developing agroforestry systems based on perennial pasture species which incur no loss of forage production.

Aims/Objectives

The aim of the project was to identify perennial forage species that compete successfully with trees for water, nutrients and light in the medium to low rainfall zone in south-west Western Australia, and to assess what effect perennial pastures have on tree root morphology and water-use compared to annual pastures.

Methods used

Ten on-farm sites were located within the medium to low rainfall zone of the south coast of Western Australia. At each site, tree-pasture systems comprised of tree belts adjoining perennial or annual pasture were compared over a period of 12 months. Measurements included pasture growth, composition and root morphology, tree water use and root morphology, soil fertility and soil water content.

Results/Key findings

Pasture growth and composition

This study found that competition between trees and pastures consistently resulted in reduced annual pasture yield within the tree root zone, by up to 53% on average, confirming the results of a number of studies undertaken in southern Australia. There was no strong evidence that the reduction could be attributed to competition for soil nutrients. However, soil water content was less in the tree root zone compared to annual pasture alone suggesting that the principle mechanism reducing pasture growth was competition for water.

In contrast to annual pasture, the average decline in perennial grass pasture yield within the tree root zone was at most 10%. Furthermore, in comparison to the open annual pasture yield, perennial grass yield was similar or greater even within 0.5 tree heights of the tree belt, suggesting perennial grasses are more successful in competing with trees for moisture, or were less affected by periodic moisture stress. These results confirm that kikuyu growth is not reduced by tree competition and that tall wheat grass, veldt grass, rhodes grass and consol lovegrass are similarly competitive with trees in medium rainfall environments.

Previous research concluded that perennial forages were generally more competitive with trees because of their deeper and denser root systems. That does not appear to be the case for lucerne in this study where yields were reduced by tree competition, on average up to 63%. This may have been due

to poor establishment when lucerne was sown into the dry soil alongside established trees or the reduced availability of phosphorus in close proximity to trees.

In this study it was difficult to draw any conclusions about the impact of tree competition on pasture nutritive value or botanical composition.

Tree water use and root morphology

Pines with a kikuyu understorey generally transpired less water compared to those with an annual pasture understorey. While the water use of kikuyu wasn't measured, it is reasonable to assume that this was due to competition between the pines and kikuyu. Measurement showed tree roots were displaced from the upper 1.8m of the soil profile by kikuyu roots. While pines with a kikuyu understorey used less water than pines with annual pasture, other studies suggest that the additional water used by the perennial pasture would more than offset reduced tree water use. Consequently, perennial pasture based agroforestry systems would be more effective than annual pasture based systems in reducing groundwater recharge.

Implications for relevant stakeholders

Perennial grasses that are drought tolerant and adapted to low fertility (eg. kikuyu, tall wheat grass, Rhodes grass, veldt grass and consol lovegrass) are better able to compete with trees than annual pastures and lucerne in the high to medium rainfall zone of southwest Australia. Other than the area directly under tree crown, agroforestry systems that include perennial grasses will produce at least similar amounts of forage to annual pastures alone. Lucerne competes poorly with trees, however pasture losses may be overcome by maintaining soil available P and establishing the trees and lucerne in the same growing season. This requires further investigation. It is likely that there will be less leakage under perennial pasture based agroforestry systems compared to annual based systems.

Undoubtedly "competitive" perennial pasture species will affect tree growth. Tree growth was not measured during this one year study, but at the 70% of sites where pasture biomass production in the root zone of trees was greater for perennial pasture than annual pasture, it is safe to assume that the perennial pasture was providing more competition with the trees for resources and so may have been reducing tree growth. If so, this will have economic implications where trees are being grown to produce commercial products but is of less importance if trees have been planted for shelter, aesthetic or landcare benefits. It is necessary to have a sound understanding of the economic consequences of both improved pasture production and any decrease in tree growth before such systems can be widely recommended to farmers.

Recommendations

The design of agroforestry systems in the south west of Australia should include drought tolerant perennial grasses if the objective is to minimise losses of forage production. Species proven to date include kikuyu, tall wheat grass, veldt grass (though there is limited seed available), Rhodes grass and consol lovegrass. It is likely that setaria, panic, digit grass and native grasses would also be competitive with trees.

Further research is required to determine the effect perennial pasture species have on the growth of commercial tree species in silvopastoral systems across a range of environments. These data should be used to assess the economics of various silvopastoral systems in a range of environments.

Further research is required to determine the best methodologies for establishing and managing perennial pastures in existing and new agroforestry systems.

1. Introduction

Recent Australian research has shown that there can be considerable losses in the productivity of annual crops and pastures alongside trees in alley and windbreak systems. While these losses can be managed in some situations by manipulating the root volume or leaf area of the trees, they remain a disincentive to producers considering adopting agroforestry systems. However, recent research and anecdotal evidence from Western Australia is pointing to the role perennial pastures may play in agroforestry systems. There are exciting new data from the Sustainable Grazing Systems (SGS) tree/pasture study showing that kikuyu pasture can be grown in the root zone of *Eucalyptus globulus* (blue gum) with no reduction in pasture productivity (Sanford *et al.* 2003). This new information opens up a number of possibilities and raises several questions.

Experimental evidence suggests alley systems in which perennial pastures are grown in the inter-rows will allow less groundwater recharge than alley systems with annual pastures (Sanford *et al.* 2003). The SGS project has highlighted a number of other benefits of perennial pastures such as increased livestock production (Sanford *et al.* 2003) and a reduction in soil erosion. The potential benefits of such systems ultimately depend on the extent of adoption in the farming community. Agroforestry is currently constrained by uncertainties about the economics of the tree component and the perceived negative impacts of trees on agricultural enterprises. Agroforestry systems in which pasture production is not reduced in the competition zone will be more attractive to farmers seeking to maintain or increase income from their agricultural enterprises, or those who are adopting these systems for the first time. Increased adoption of agroforestry, where the beneficial effects of trees are integrated with agriculture, would involve farmers staying on the land and continuing agricultural production.

The challenge to developing viable agroforestry systems incorporating perennial pastures lies in identifying and proving a range of perennial pasture species tolerant of competition with trees and suited to various soils and rainfall zones. Undoubtedly such “competitive” pasture species will affect tree growth; it is necessary to have a sound understanding of the economic consequences of both improved pasture production and any decrease in tree growth before such systems can be widely recommended to farmers.

1.1 Study aim/objective

To identify perennial forage species that compete successfully with trees for water, nutrients and light in the medium to low rainfall zone in south-west Western Australia (WA), and to assess what effect perennial pastures have on tree root morphology and water-use compared to annual pastures.

2. Methodology

2.1 Sites

Ten on-farm sites were located within the medium to low rainfall zone (350 to 600 mm annual rainfall) of the south coast of WA. Site location is given in Table 1, along with annual rainfall, soil type and pasture and tree characteristics. Soil chemical analyses for each site are presented in Table 2.

2.2 Experimental layout

At each site, three transects were established in each pasture treatment (annual and perennial) at 90 degrees to the tree belt. Measurement/sampling points for soil, pasture and roots were located along these transects at 0.5, 1, 2 and 4 times the tree height (H) from the tree stem. See Appendix 7.3 for detailed site layout and location.

2.3 Management

At all sites, pasture and livestock management was undertaken by the farmer.

2.4 Measurements

2.4.1 Rainfall

Rainfall data were obtained from SILO (www.nrm.qld.gov.au/silo/datadrill/).

2.4.2 Soil

2.4.2.1 Soil chemical analyses

Soil cores (0 – 0.1 m depth) were taken at all sites in late summer-autumn 2004 (2002 at Site H) prior to the break-of-season. Transects running perpendicular to the tree line were marked at each site. Samples were taken along each transect in both perennial and annual pastures at the distances described previously. Samples were dried at 40°C and passed through a 2 mm sieve. All samples were sent to the State Chemical Laboratory, Western Australia for analysis. Samples were analysed for pH (CaCl₂), organic C, total N, available P, available K and exchangeable cation concentrations for Ca, Mg, Na, K, Al, Mn.

2.4.2.2 Soil water content

Soil water content was measured at Sites D, G and H at the same time the root measurements were taken (Site H: April 2002, Site G: March 2004, Site D: April 2004). Trenches were excavated parallel to the tree line along each transect at 0.5, 0.1, 1.5, 2.0, 2.5 and, 3.0 H at Site H and 0.5, 1.0, 2.0 and 4.0 H at Sites D and G. Trenches were generally 1.5 m deep, though some were shallower where cemented laterite impeded the excavator, and had at least 2 - 4 m of vertical trench wall running parallel to the trees. One trench was dug at each distance at Site H and three trenches at the other sites.

Soil samples were collected from each trench. Immediately prior to sampling, the trench wall was cut back to reveal fresh soil, then samples were taken at 0.1 m intervals down to the pit floor and sealed into plastic bags. The wet weight of the samples was determined and then the samples were dried at 110 °C for 48 hrs and weighed again. At Site H, bulk density was determined by taking volumetric soil samples at 0.1 m intervals down the soil profile. Bulk density was used to convert gravimetric water content to volumetric water content at Site H.

Note: 25 mm of rain fell between taking the soil water content samples for the trees plus annual pasture and trees plus perennial pasture at Site H.

Table 1. Site location, farmer's name, annual rainfall, soil type and pasture and tree characteristics.

Site	Farmers surname	Location	Annual rainfall	Pasture type and species	Tree species	Soil type	Age (yr)	Height (m)	Diameter (cm)	Tree volume (m ³)	Tree spacing (m)	Root pruned depth (m)	Years	Orientation	Aspect
A	Thomson	117°09'20E 33°34'00S	431	Tall wheat grass Annual	<i>Eucalyptus spp.</i>	Sand/clay	15+	12.0	41.7	0.346	Various	No		West	10'
								12.0	41.7			No		East	10'
B	Pickford	117°13'50E 33°32'41S	426	Lucerne Annual	Mallee (<i>Eucalyptus spp.</i>)	Red clay loam		5.7	18.5	0.051		No		East	0'
								5.4	23.0	0.075		No		West	0'
C	Shearer	118°16'38E 34°33'23S	500	Lucerne Annual	<i>Pinus pinaster</i>	Sand	10	6.5 5.5	13.7 13.5	0.032 0.026		No No		West West	290' 320'
D	Subassio	118°30'58E 34°23'04S	459	Veldt grass Annual	<i>P. pinaster</i>	Sand/clay Deep sand/clay	10	7.5	16.6	0.054		No		East	340'
								10	31.8	0.265		No		East	10'
E	Caelli	119°43'15E 34°40'11S	425	Veldt grass Annual	<i>E. gomphocephala / Hakea spp.</i>	Sand						No No		West East	340' 340'
F	Tuckett	120°08'53E 33°16'42S	359	Lucerne Annual	Mallee (<i>Eucalyptus spp.</i>)	Clay /gravel	19					No		East	0'
												No		East	340'
G	Silburn	120°44'56E 33°47'19S	450	Kikuyu African lovegrass Annual	<i>P. pinaster</i>	Sand /gravel	40	20	51.5	1.389		No		East	10'
							40	20	44.3	1.028		No		East	10'
							38	20	46.6	1.137		No		East	55'
H	Johnson	121°44'06E 33°41'00	546	Kikuyu Annual	<i>P. pinaster</i>	Sand/clay	50	17	54.2	1.307		No		West	355'
								18	59.2	1.652		No		West	355'
I	DeGrussa	122°03'17E 33°37'08S	471	Annual	<i>P. pinaster</i>	Sand /gravel	30	13	37.8	0.494		Yes		East	50'
I	Godfrey	122°03'17E 33°37'08S	471	Rhodes grass and kikuyu	<i>P. pinaster</i>	Sand	10	11.2				No		East	50'
J	Johnstone	122°14'57E 33°40'12	516	Lucerne Annual	<i>Eucalyptus globulus</i>	Sand	13	12 17.5	17	0.091		Yes Yes		East East	40' 40'

Table 2. Soil chemical characteristics in the top 0.1 m of the soil profile under various pasture species.

Site	Pasture type	pH (CaCl ₂)	P (mgP/kg)	K (mgK/kg)	Organic C (%)	Total N (%)	Ca (me%)	Mg (me%)	Na (me%)	K (me%)	Al (me%)	Mn (me%)
A	Annual	4.5	54	39	1.71	0.134	2.05	1.15	1.48	0.11	0.24	<0.02
	Tall wheat grass (<i>Thinopyrum elongatum</i>)	4.8	23	80	2.37	0.182	4.71	1.99	1.89	0.30	0.06	0.05
B	Annual	5.5	87	160	3.93	0.261	8.12	2.11	0.90	0.36	0.06	0.04
	Lucerne (<i>Medicago sativa</i>)	5.4	64	76	2.74	0.197	5.81	1.34	0.44	0.15	0.05	0.06
C	Annual	5.0	7	68	1.80	0.142	5.43	0.75	0.12	0.22	0.02	0.02
	Lucerne	4.8	15	180	2.47	0.185	3.97	1.23	0.21	0.44	0.14	0.02
D	Annual	5.2	13	61	2.04	0.134	3.80	0.90	0.17	0.15	0.02	<0.02
	Veldt grass (<i>Ehrharta calycina</i>)	4.9	9	40	1.02	0.079	1.41	0.39	0.06	0.12	0.05	<0.02
E	Annual	4.9	19	66	1.20	0.091	3.28	0.53	0.18	0.23	0.06	<0.02
	Veldt grass	4.6	17	65	1.25	0.085	2.08	0.30	0.05	0.19	0.11	<0.02
F	Annual	4.9	20	73	0.92	0.054	2.91	0.52	0.29	0.17	0.13	0.02
	Lucerne	4.8	26	130	1.32	0.067	2.01	0.48	0.44	0.30	0.12	<0.02
G	Annual	4.8	7	58	1.35	0.096	2.44	0.51	0.11	0.16	0.09	<0.02
	Kikuyu (<i>Pennisetum clandestinum</i>)	5.0	8	77	1.37	0.093	2.08	0.52	0.04	0.18	0.03	<0.02
	Consol lovegrass	4.8	6	51	1.14	0.084	2.45	0.43	0.05	0.12	0.05	<0.02
H	Annual	4.6	12	91	1.81	0.144	2.90	0.56	0.13	0.24	0.09	<0.02
	Kikuyu	4.6	11	82	1.55	0.117	1.79	0.50	0.06	0.20	0.06	<0.02
I	Annual	4.4	12	39	1.09	0.094	1.61	0.35	0.12	0.10	0.14	0.02
	Rhodes grass (<i>Chloris gayana</i>) /kikuyu	5.2	22	90	1.15	0.092	2.60	0.48	0.05	0.22	0.04	0.03
J	Annual	4.6	12	39	0.82	0.067	1.24	0.18	0.05	0.09	0.05	0.02
	Lucerne	5.2	22	90	1.15	0.092	2.60	0.48	0.05	0.22	0.04	0.03

2.4.3 Pasture

All pasture measurements were taken at 0.5, 1, 2 and 4 H along each transect at each site.

2.4.3.1 Pasture growth

Pasture growth was estimated by measuring herbage mass accumulation in 1 m² exclusion cages. Herbage mass was determined using the calibrated visual assessment technique of Campbell and Arnold (1973). One exclusion cage was placed in each sampling point. Measurements were taken every 4 weeks. At each sampling, 15 calibration quadrats (0.1m²) were cut to ground level with a scalpel, to relate visual estimates to actual herbage mass. Total pasture yield was determined by totalling growth for the calendar year.

2.4.3.2 Botanical composition

Botanical composition was estimated every 4 weeks using BOTANAL ('t Mannetje and Haydock 1963) with the modifications proposed by Jones and Hargreaves (1979). Species were ranked first, second or third according to their estimated contribution to dry pasture herbage mass. Estimates were taken on the pasture adjacent to the exclusion cages.

2.4.3.3 Nutritive value

All sites were sampled for pasture nutritive value once in spring 2004. Samples were taken at all sampling locations along each transect by cutting a small area of pasture to ground level. Samples from different transects but the same distance from the trees within the same pasture type were bulked for analysis. Samples were washed, dried at 60°C for 48 hours and then ground with a hammer mill and passed through a 1 mm screen. Samples were analysed at the Department of Agriculture, Feed Analysis Laboratory for dry matter digestibility (%DMD) using the pepsin-cellulase technique and crude protein (%CP) using Kjeldahl digestion.

2.4.4 Trees

2.4.4.1 Sapflow

Tree water use was measured at Site H using the sap flow velocity method. Heat pulse velocity was measured using Greenspan Loggers equipped with Greenspan SF300a probe sets. Sap flow was determined using the compensation method to determine sap velocity (Swanson and Whitfield, 1981; Barrett *et al.*, 1995; Morris *et al.*, 1995) and the weighted average technique of Hatton *et al.* (1990) to determine sap flow.

Three trees with an annual pasture understorey and four trees with a kikuyu understorey were measured; these trees represented the range of tree diameters present at the site. Probes were installed at breast height (1.3 m) on the northern, southern, eastern western sides of each stem. Each probe was installed at a different depth into the sapwood of the tree. Heat pulse velocity was measured and logged every 30 minutes.

The area of sapwood was determined by taking four cores from the tree stem in which the sensors were installed using a 5 mm diameter increment corer. The cores were then used to determine the width of the heartwood, sapwood and cambium. For pines, heartwood was differentiated from sapwood by a basic indication when tested by pH indicator Bromcresol green.

The volume fractions of sapwood and of water were calculated by Archimedes' principle Anon (1996). Samples were taken from the cores used to determine sapwood area. The volume fractions of wood and water were 0.43 and 0.35 respectively. The width of the wound around the probes was determined by sampling trees in which probes had been installed for at least a month; mean wound width in these trees was 0.82 mm on each side of the hole giving a total wound width of 3.65 mm.

Table 3. Dates when sapflow data were collected from each tree.

Pasture type	Tree number	Measurement period
Annual	A1	5/12/03-11/1/05
	A2	5/12/03-11/1/05
	A3	5/12/03-22/4/04, 30/4/04-11/1/05
Kikuyu	P1	5/12/03-11/1/05
	P2	5/12/03-11/3/04, 31/3/03-29/10/04, 7/12/04-11/1/05
	P3	5/12/03-20/2/04, 12/3/04-29/10/04, 7/12/04-11/1/05
	P4	16/3/04-1/9/04, 29/9/04-29/10/04, 7/12/04-11/1/05

The periods over which each individual tree was measured are shown in Table 3. Missing data for tree P3 from 23-29 March 2004 were estimated using the relationship between P1 and P3 water use in the days immediately before and after the period for which data were unavailable. Missing data for trees A1, A3 and A4 (2-28/4/04 and 30/10-6/12/04 only) were estimated in a similar way using tree A1 as the reference tree. After installation, probes were relocated twice during the measurement period.

2.4.5 Roots

2.4.5.1 Root distribution

The distribution of tree roots in the soil adjacent to the tree lines was mapped at Sites D, G and H using a trench profile method similar to that described by Bohm (1979). Measurements were made in the trenches from which soil samples were taken (refer 2.4.2.2).

In each trench, the wall nearest the tree line was smoothed to provide a surface upon which to work. To reveal the tree roots, sand was gently removed from the face using a brush, and clay was removed using a water spray. About 2 mm of sand and 1 mm of clay was removed in this way. Two (six at Site H) clear plastic sheets (each 0.5 m wide and 1.4 m long) were then fixed over the prepared trench wall, running from the soil surface to 1.4 m deep. All of the tree root and soil features were traced onto the plastic. Root diameters were indicated on the sheets according to the following size classes; ≤ 2 mm (fine roots), > 2 to ≤ 5 mm, > 5 to ≤ 10 mm, > 10 to ≤ 20 mm, and > 20 mm. The number of root intercepts for each root size class were counted and recorded for each 0.1 m depth interval.

2.4.5.2 Root biomass

The weight of tree roots in the sandy soil horizons was determined for 105 mm deep increments down to the depth of clay. A steel frame (105 mm deep x 505 mm long x 40 mm wide (0.0021 m^3)) was pressed into the smoothed wall of each trench (three in each trench at Site H). A knife was run along the back of the frame to loosen the soil and sever any roots the soil and roots were then carefully removed from the frame and bagged. Roots were separated from the soil by washing the soil through a 0.71 mm sieve, then the tree roots were separated by hand from other organic matter. The tree roots were dried at 70°C for 24 hrs and weighed.

2.4.5.3 Root length and surface area

Roots harvested for biomass assessment at sites D and G (see 2.4.5.2 Root biomass) were cleaned of large to medium debris and dead roots and then split into two equal samples. One sample was used to determine root biomass; the other root length and surface area. The samples to be analysed for length and area were stored in a 10% alcohol solution at 4°C for later analysis. For analysis the sample was spread in a perspex tray and scanned using an Epson Perfection 4870 Photo high resolution flatbed scanner. Large samples were sub-sampled until individual roots could be distinguished by the scanner. The root images were analysed for length and area using the WinRHIZO (Regent Instruments Inc., Quebec, Canada) image analyses software.

3. Results

3.1 Soil chemistry

Soil pH values and nutrient concentrations showed considerable variation between sites and perennial and annual pasture treatments, reflecting differences in soil type and management history. To examine trends within the tree root zone across sites, values were normalised using values at 4 H for each particular site and pasture treatment. The actual values are presented in Appendix 7.1, Figures 11-14.

Overall, topsoil in close proximity to tree belts (0.5, 1 and 2 H) was more acid than in open pasture (Table 4). However, the decline was very modest; between 1 and 3% for annual and perennial grass pasture and between 2 and 5% for lucerne. In 42% of cases (9 out of 21), there was no change in soil pH between the open pasture condition and 0.5, 1 and 2 H. At Site A, tall wheat grass, Site B annual and lucerne, Site D veldt grass, Site I Rhodes grass/kikuyu and Site J, lucerne soil pH declined consistently from 4 H to 0.5H (Figure 11a, b, d, i and j). In contrast, soil pH was higher at 0.5 H relative to open pasture at Site F annual, Site G annual and consol lovegrass and Site H annual and kikuyu (Table 4).

Table 4. Percent change in soil pH(CaCl₂) in top 0.10 m in relation to conditions at 4 H.

Site	Pasture type	Distance from trees (H)			
		0.5	1	2	4
A	Annual	98	98	98	100
	Tall Wheat grass	88	90	96	100
B	Annual	91	98	100	100
	Lucerne	91	94	98	100
C	Annual	100	100	98	100
	Lucerne	98	94	94	100
D	Annual	96	98	100	100
	Veldt grass	94	98	98	100
E	Annual	100	100	98	100
	Veldt grass	100	104	100	100
F	Annual	102	100	98	100
	Lucerne	96	102	100	100
G	Annual	104	100	100	100
	Kikuyu	100	100	102	100
	Consol lovegrass	104	102	102	100
H	Annual	104	100	100	100
	Kikuyu	107	98	100	100
I	Annual	98	100	95	100
	Rhodes grass/kikuyu	92	92	92	100
J	Annual	98	96	96	100
	Lucerne	93	96	100	100
Mean ± SE	Annual	99 ± 1	99 ± 1	98 ± 1	100
	Perennial	97 ± 2	97 ± 1	98 ± 1	100
	Perennial grass	98 ± 3	98 ± 2	99 ± 1	100
	Lucerne	95 ± 2	97 ± 2	98 ± 1	100

As for soil pH, there was a general trend for soil K and N to be less in the tree root zone compared to at 4 H, however, differences were not significant (Tables 5 and 7). The concentration of P in the soil was highly variable between distances within sites, and was generally greater within the root zone across all sites. However for sites with lucerne there was less P within the root zone of trees compared to at 4 H (Table 6).

Table 5. Percent change in soil total N (%) in the top 0.10 m in relation to conditions at 4 H.

Site	Pasture type	Distance from trees (H)			
		0.5	1	2	4
A	Annual	69	98	91	100
	Tall Wheat grass	55	64	88	100
B	Annual	79	85	91	100
	Lucerne	111	96	115	100
C	Annual	86	102	87	100
	Lucerne	97	86	94	100
D	Annual	49	87	76	100
	Veldt grass	99	100	172	100
E	Annual	115	110	125	100
	Veldt grass	96	96	92	100
F	Annual	100	94	113	100
	Lucerne	49	81	91	100
G	Annual	96	116	92	100
	Kikuyu	84	104	110	100
	Consol lovegrass	101	105	106	100
H	Annual	94	97	101	100
	Kikuyu	112	109	143	100
I	Annual	103	128	101	100
	Rhodes grass/kikuyu	78	100	107	100
J	Annual	106	122	122	100
	Lucerne	109	105	126	100
Mean ± SE	Annual	90 ± 6	104 ± 5	100 ± 5	100
	Perennial	90 ± 7	95 ± 4	113 ± 8	100
	Perennial grass	89 ± 7	97 ± 6	117 ± 11	100
	Lucerne	92 ± 15	92 ± 5	107 ± 8	100

Table 6. Percent change in soil available P (ppm) in the top 0.10 m in relation to conditions at 4 H.

Site	Pasture type	Distance from trees (H)			
		0.5	1	2	4
A	Annual	50	33	46	100
	Tall Wheat grass	161	161	113	100
B	Annual	37	80	70	100
	Lucerne	61	66	78	100
C	Annual	71	100	100	100
	Lucerne	40	47	73	100
D	Annual	85	92	54	100
	Veldt grass	67	56	100	100
E	Annual	111	116	89	100
	Veldt grass	100	94	106	100
F	Annual	120	90	110	100
	Lucerne	65	142	135	100
G	Annual	200	129	100	100
	Kikuyu	150	113	100	100
	Consol lovegrass	250	117	67	100
H	Annual	142	133	133	100
	Kikuyu	191	118	109	100
I	Annual	133	100	125	100
	Rhodes grass/kikuyu	59	59	55	100
J	Annual	58	67	117	100
	Lucerne	67	67	83	100
Mean ± SE	Annual	101 ± 16	94 ± 9	94 ± 9	100
	Perennial	110 ± 21	95 ± 12	93 ± 7	100
	Perennial grass	140 ± 26	103 ± 14	93 ± 9	100
	Lucerne	58 ± 6	81 ± 21	92 ± 14	100

Table 7. Percent change in soil available K (ppm) in the top 0.10 m in relation to conditions at 4 H.

Site	Pasture type	Distance from trees (H)			
		0.5	1	2	4
A	Annual	136	126	136	100
	Tall Wheat grass	74	125	78	100
B	Annual	47	69	81	100
	Lucerne	224	224	117	100
C	Annual	62	65	85	100
	Lucerne	29	36	37	100
D	Annual	213	59	66	100
	Veldt grass	50	70	118	100
E	Annual	97	152	102	100
	Veldt grass	75	97	74	100
F	Annual	107	90	110	100
	Lucerne	65	142	135	100
G	Annual	50	67	67	100
	Kikuyu	52	65	103	100
	Consol lovegrass	86	55	49	100
H	Annual	80	95	88	100
	Kikuyu	159	116	99	100
I	Annual	128	205	90	100
	Rhodes grass/kikuyu	29	59	51	100
J	Annual	54	38	49	100
	Lucerne	71	75	154	100
Mean ± SE	Annual	97 ± 16	97 ± 16	87 ± 8	100
	Perennial	83 ± 18	97 ± 16	92 ± 11	100
	Perennial grass	75 ± 16	84 ± 11	82 ± 10	100
	Lucerne	97 ± 43	119 ± 41	111 ± 26	100

3.2 Soil water content

At Sites G and H, the depth to clay was similar for the perennial and annual pasture treatments and remained relatively constant with distance from the trees. At these sites, for trees with annual pasture, soil water content (SWC) was generally less within the root zone of the trees compared to outside the root zone (Figures 1a and 2a). This trend was evident both in the sandy topsoil and clay subsoil. However for trees with perennial pasture, SWC was relatively similar inside and outside of the tree root zone (Figures 1b and 2b). Within 2 H, the SWC was similar in the top soil of trees with annual pasture and trees with perennial pasture, but greater in the clay subsoil of trees with perennial pasture compared to trees with annual pasture. Outside of the tree root zone, SWC was less in trees with perennial pasture compared to trees with annual pasture. It should be noted that the higher soil water content in the top 0.4 m of the annual pasture compared to the perennial pasture at Site H was due to 25 mm of rain falling in the week between measuring the two treatments (Figure 1a).

At Site D, depth to clay was highly variable both between and within treatments; in the annual pasture treatment it ranged from 0.6 m at 0.5 H to 0.8 m at 4 H and from 0.2 m at 0.5 H to 0.15 m at 0.4 H in the perennial pasture treatment. These differences in depth to clay confounded any interpretation of the relationship between tree root distribution and density and soil water content (Figure 2b and c).

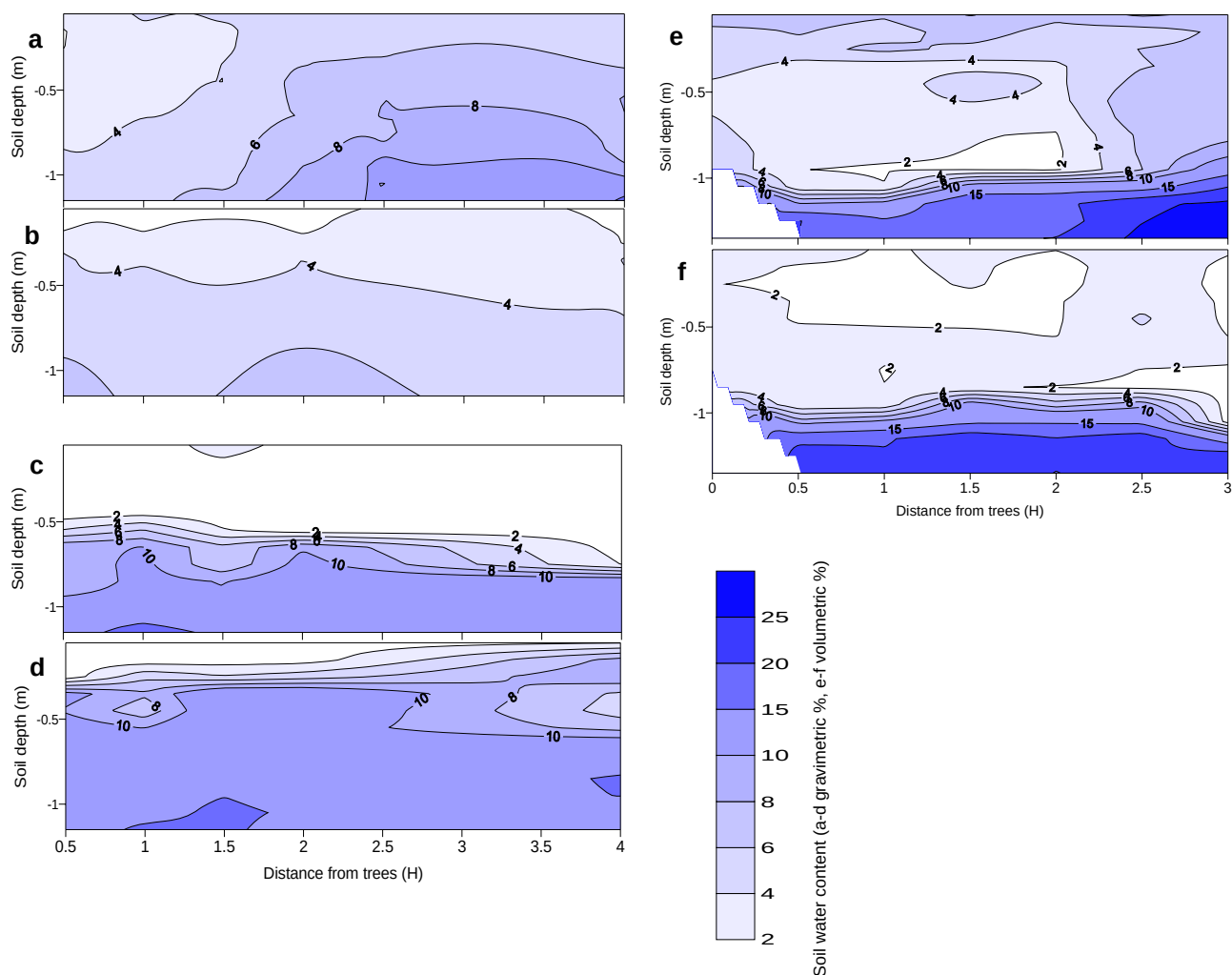


Figure 1. Gravimetric soil water content at various distances from tree lines at Site G annual pasture (a), Site G perennial pasture (b), Site D annual pasture (c) and Site D perennial pasture (d) and volumetric soil water content at Site H annual pasture (e) and Site H perennial pasture (f). Contour maps a, b, e and f drawn using krigging and c and d using triangulation with linear interpolation.

3.3 Pasture

3.3.1 Lucerne plant density

The density of lucerne plants at Site J was measured five months after sowing in late 2002 (Sudmeyer, unpublished data). Establishment was poor within 1 H of the trees but similar to open conditions at 1.5 H and beyond (Figure 2).

3.3.2 Pasture yield

Relative to open pasture for that pasture type, pasture yield was reduced in close proximity to tree belts (up to 97% at 0.5 H at Site F) at all but two sites (Figure 3, Table 8). At Sites D and Site H, kikuyu and veldt grass produced as much dry matter at 0.5 H as they did at 4 H. Interestingly, the depression in average yield at 0.5 H across sites, varied significantly between pasture types. Annual pasture and lucerne yielded only 47 and 37% respectively in this zone compared to 89% for perennial grasses.

At 1 and 2 H, changes in pasture yield relative to pasture at 4 H varied from 30% to 161%. However, at 60% of sites there was a depression in yield. Overall, annual pasture and lucerne recorded losses in production at 1 H of 15% and 55% respectively compared to only 4% for perennial grasses. At 2 H both annual pasture and perennial grasses recorded no loss in pasture production while lucerne was still only 75% of pasture at 4 H.

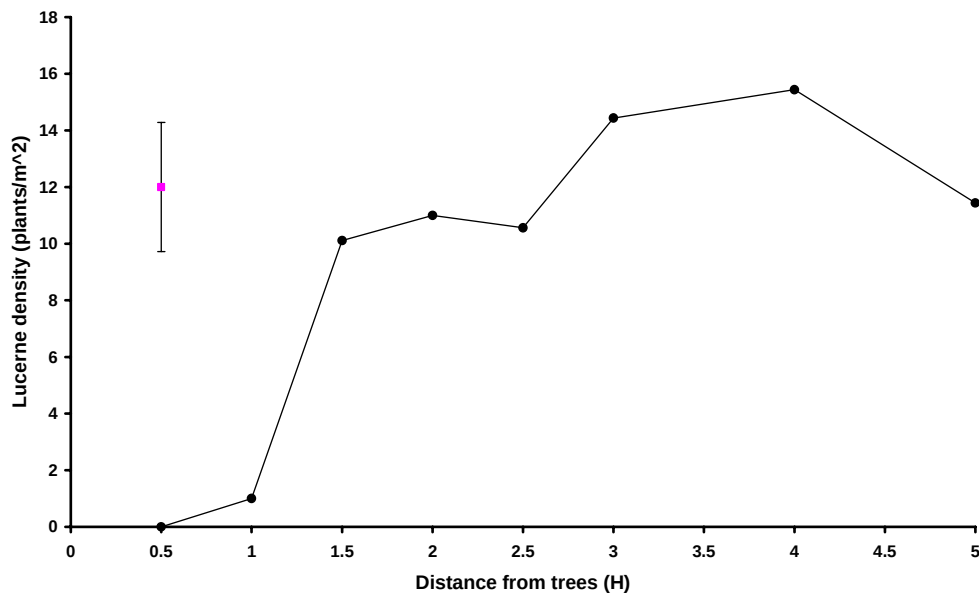


Figure 2. Lucerne plant density (plants/m²) in relation to the distance (tree heights H) from the tree belt at Site J. Error bar shows LSD ($P < 0.05$).

An alternative way to analyse the data is to compare the relative yield of the perennial pasture to the open annual pasture yield at 4 H. While some caution has to be exercised in this comparison as it is likely that the soil conditions for the annual and perennial pasture are different, it is a useful analogy to replacing annual pasture with an agroforestry system that includes perennial pasture. Interestingly, at 63% of sites perennials yielded more than annual pasture in open pasture conditions (Table 8). In the case of lucerne open pasture yield was 45% higher compared to only 6% for perennial grasses. In contrast, perennial grass yield was equal to open annual pasture yield at 0.5, 1 and 2 H while lucerne yield declined significantly at 0.5 and 1 H.

In addition to the recorded increases in annual yield from perennials both in the presence and absence of tree competition, patterns of cumulative dry matter yield across all sites consistently demonstrated that perennial pastures produced dry matter outside the growing season in summer and autumn (Figure 8) compared to annual pastures. In some cases, perennials at 0.5 H produced more dry matter than those at 1, 2 and 4 H (Sites A, D, G2 and I, Figure 8).

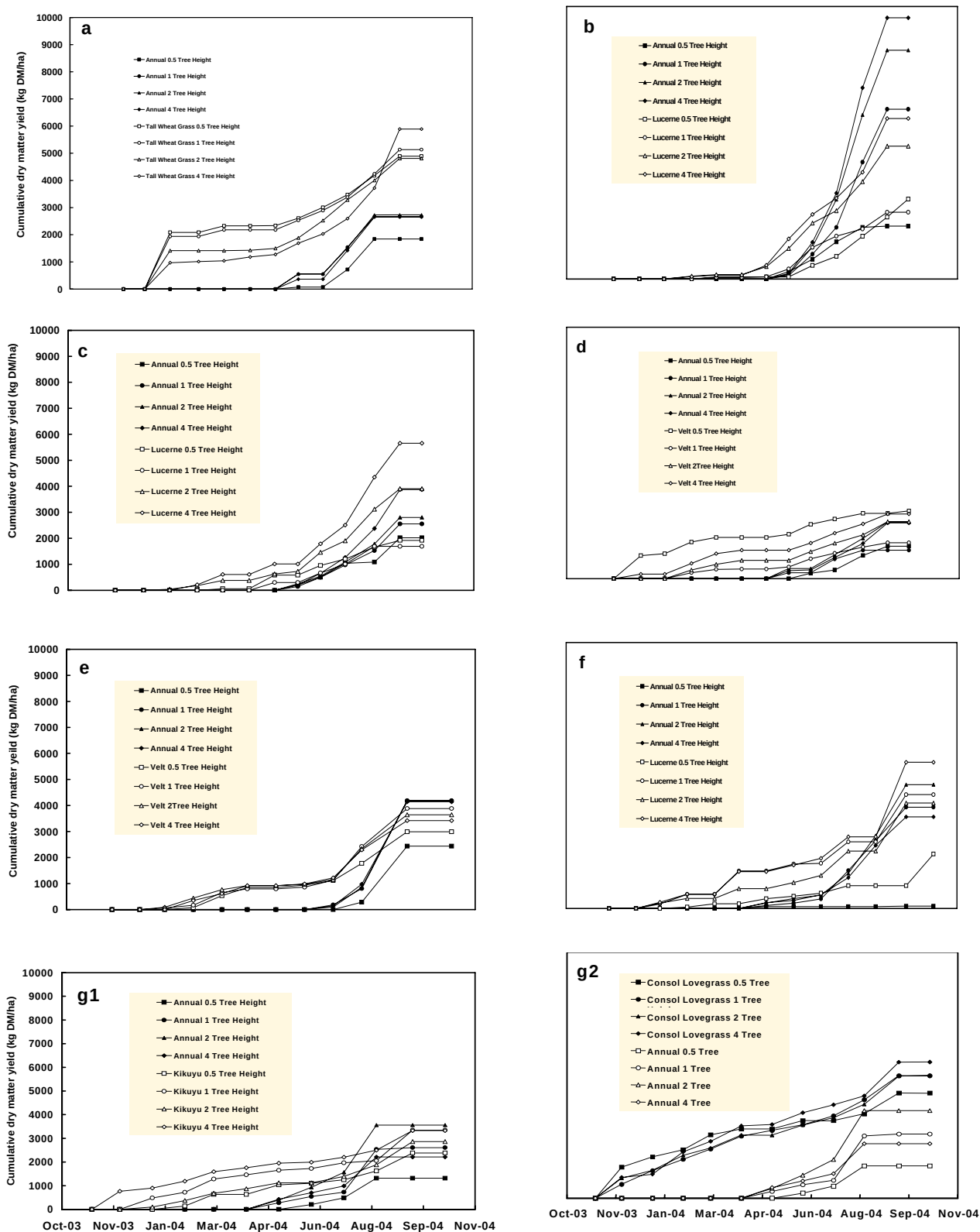


Figure 3. Cumulative dry matter yield at Site A (a), Site B (b), Site C (c), Site D (d), Site E (e), Site F (f), Site G kikuyu (g1), Site G consol lovegrass (g2).

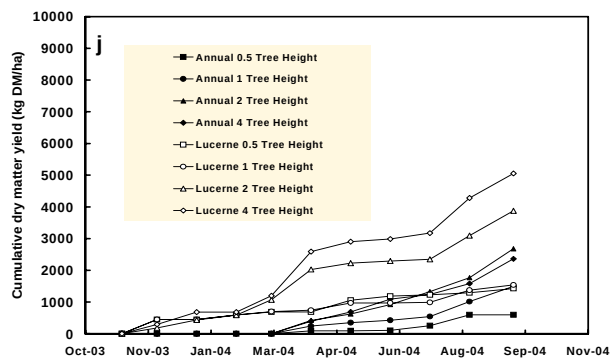
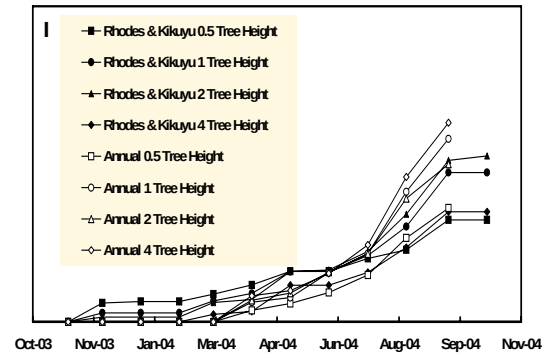
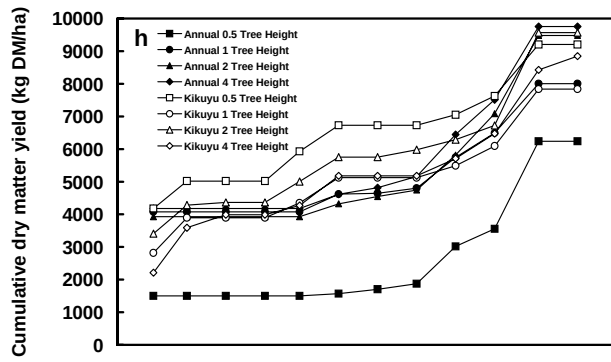


Figure 3 cont... Cumulative dry matter yield at Site H (h), Site I (i) and Site J (j).

Table 8. Percent pasture yield (DM/yr) relative to annual or perennial pasture yield at 0.4 H at a particular site, or relative to annual pasture yield at 0.4 H only at a particular site.

Site	Pasture type	Pasture yield relative to open for each pasture type (%)				Pasture yield relative to open annual pasture (%)			
		0.5	1	2	4	0.5	1	2	4
A	Annual	69	101	103	100	69	101	103	100
	Tall Wheat grass	83	87	82	100	184	194	181	222
B	Annual	20	65	88	100	20	65	88	100
	Lucerne	50	42	83	100	24	26	51	61
C	Annual	52	66	72	100	52	66	72	100
	Lucerne	34	30	69	100	50	44	101	146
D	Annual	58	51	102	100	58	51	102	100
	Veldt grass	105	56	88	100	122	64	102	116
E	Annual	59	101	101	100	59	101	101	100
	Veldt grass	88	114	107	100	72	94	88	82
F	Annual	3	111	135	100	3	111	135	100
	Lucerne	37	78	72	100	59	124	115	160
G	Annual	60	118	161	100	60	118	161	100
	Kikuyu	72	101	86	100	108	151	129	150
	Consol	77	90	90	100	193	225	225	250
	lovegrass								
H	Annual	64	82	97	100	64	82	97	100
	Kikuyu	104	89	108	100	94	80	98	91
I	Annual	57	92	79	100	57	92	79	100
	Rhodes grass / kikuyu	93	136	151	100	51	75	83	55
J	Annual	25	63	114	100	25	63	114	100
	Lucerne	28	30	77	100	60	65	164	214
Mean ± SE	Annual	47 ± 7	85 ± 7	105 ± 8	100	47 ± 7	85 ± 7	105 ± 8	100
	Perennial	70 ± 9	78 ± 10	92 ± 7	100	85 ± 17	95 ± 19	111 ± 15	120 ± 19
	Perennial grass	89 ± 5	96 ± 9	102 ± 9	100	103 ± 20	110 ± 24	113 ± 20	106 ± 26
	Lucerne	37 ± 5	45 ± 11	75 ± 3	100	48 ± 8	65 ± 21	108 ± 23	145 ± 32

3.3.3 Pasture nutritive value

Pasture dry matter digestibility (DMD) was generally variable at various distance from the trees, the only consistent trends were at Sites B, C and G (Figure 4). At these sites, DMD was less close to the tree belt compared to at 4 H. However, there was no change in DMD associated with a particular pasture species. Pasture DMD declined for annual pasture at Site B, both annual and lucerne pasture at Site C and for Rhodes grass and kikuyu at Site G.

Changes in pasture crude protein in response to tree competition were also highly variable (Figure 4). At Site A and D crude protein was similar at 0.5, 1 and 2 H compared with the open pasture condition (the exception being a greater crude protein value at 0.5 H in the veldt grass pasture at Site D). While crude protein increased further from the tree belts at Site B, C and H it declined at Site G.

3.3.4 Pasture botanical composition

Pasture botanical composition is presented in Appendix 7.2, Figures 15-25. As expected perennials which competed well with trees (kikuyu, tall wheat grass, veldt grass, rhodes grass, and consol lovegrass) made up a substantial proportion of the pasture within 0.5 tree heights of the tree belt at the sites where they were present. Whereas lucerne which was less competitive was either absent or a minor pasture component

within 0.5 tree heights but abundant further away at 2 to 4 tree heights. Amongst the annual pasture species the grasses (ryegrass, barley grass and silver grass) tended to be more abundant within the competition zone at 0.5 tree heights. This was particularly true of annual ryegrass which occurred at most sites and made up a high proportion of the species within this zone. Interestingly a number of the broad leaf species (subterranean clover, capeweed and erodium) were both absent and abundant in the tree competition zone at 0.5 tree heights depending on site and season. This suggests there were other factors as well as tree competition determining their distribution within the sites investigated.

3.4 Tree water use

Rainfall at Site H in 2003 was above average at 648 mm, and slightly below average at 448 mm in 2004. Mean rainfall from 1991 to 2004 was 488 mm (Figure 5b). When measurements commenced in December 2003, the mean water use of *P. pinaster* trees with kikuyu pasture was greater than the water use of *P. pinaster* with annual pasture and greater than at any other time in the 13 month measurement period (Figure 5a). During January 2004, the water use of trees with kikuyu pasture declined and was less than the water use of trees with annual pasture until September 2004, after which it was greater. The water use of trees in both treatments increased in autumn and spring, particularly during periods with warmer temperatures following rainfall.

Compared to trees with kikuyu pasture, the water use of trees with annual pasture was relatively constant until September 2004 when it showed a sharp decline. Abrupt spikes in tree water use (trees with kikuyu pasture in autumn and trees with annual pasture in spring) were associated with heavy rainfall and an increase in pasture growth followed by a drier period (Figure 5).

The relationship between tree diameter and sapwood area was similar for trees with annual or perennial pasture understorey (Figure 6). However, there were differences in the relationship between sapwood area and sap velocity between trees with kikuyu or annual pasture.

There was a general trend for sap velocity to increase with sapwood area for trees with kikuyu pasture throughout the measurement period (Figure 7). This trend was also evident in trees with annual pasture between March and September 04. During this period, sap velocity was greater in trees with annual pasture compared to trees with kikuyu pasture for trees with similar sapwood area, though the rate of increase in sap velocity with sapwood area for trees with annual pasture was less than for trees with kikuyu pasture. After September 2004, sap velocity declined with sapwood area for trees with annual pasture and for larger trees was less than the sap velocity of trees with kikuyu pasture.

The mean water use of trees with similar sapwood areas in the two pasture treatments showed similar trends to the mean water use of all measured trees in each treatment, i.e. the water use of trees with kikuyu pasture was less than trees with annual pasture until September 2004 after which it was greater than for trees with annual pasture.

During the period December 03 to January 05, tree water use ranged between 6 and 1039 l/day for trees with kikuyu pasture and 6 and 658 l/day for trees with annual pasture. Cumulative water use over that period was 72,363 l/tree for trees with kikuyu pasture and 91,529 l/tree for trees with annual pasture. This equates to 242 and 307 mm of water removed from the root zone of trees with kikuyu pasture and trees with annual pasture respectively, where rainfall over the period was 470 mm. The root zone of the trees was defined as the area extending 2.75 H or 48.1 m from the stem into the adjacent pasture plus 1.5 m into the tree inter-row and 3 m either side of the tree along the tree line, i.e. 298 m².

If the cumulative water use for trees with similar sapwood areas is compared over the period 16 March 2004 to 11 January 2005, mean water use was 36,211 l/tree for trees with kikuyu pasture and 61,318 l/tree for trees with annual pasture.

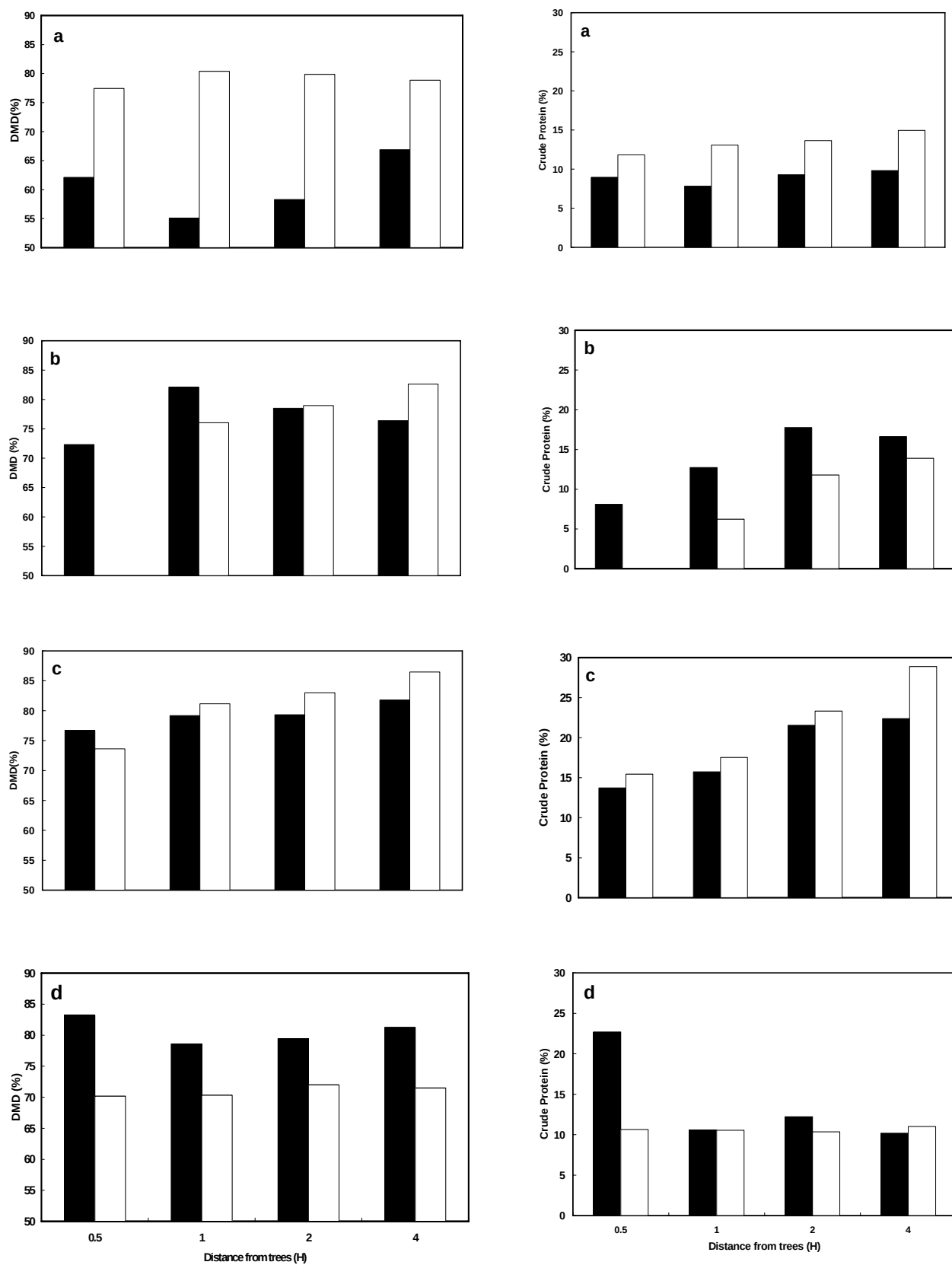


Figure 4. Pasture dry matter digestibility (DMD) and crude protein for annual pasture (open bar) or perennial pasture (closed bar) at Site A (a), Site B (b), Site C (c) and Site D (d).

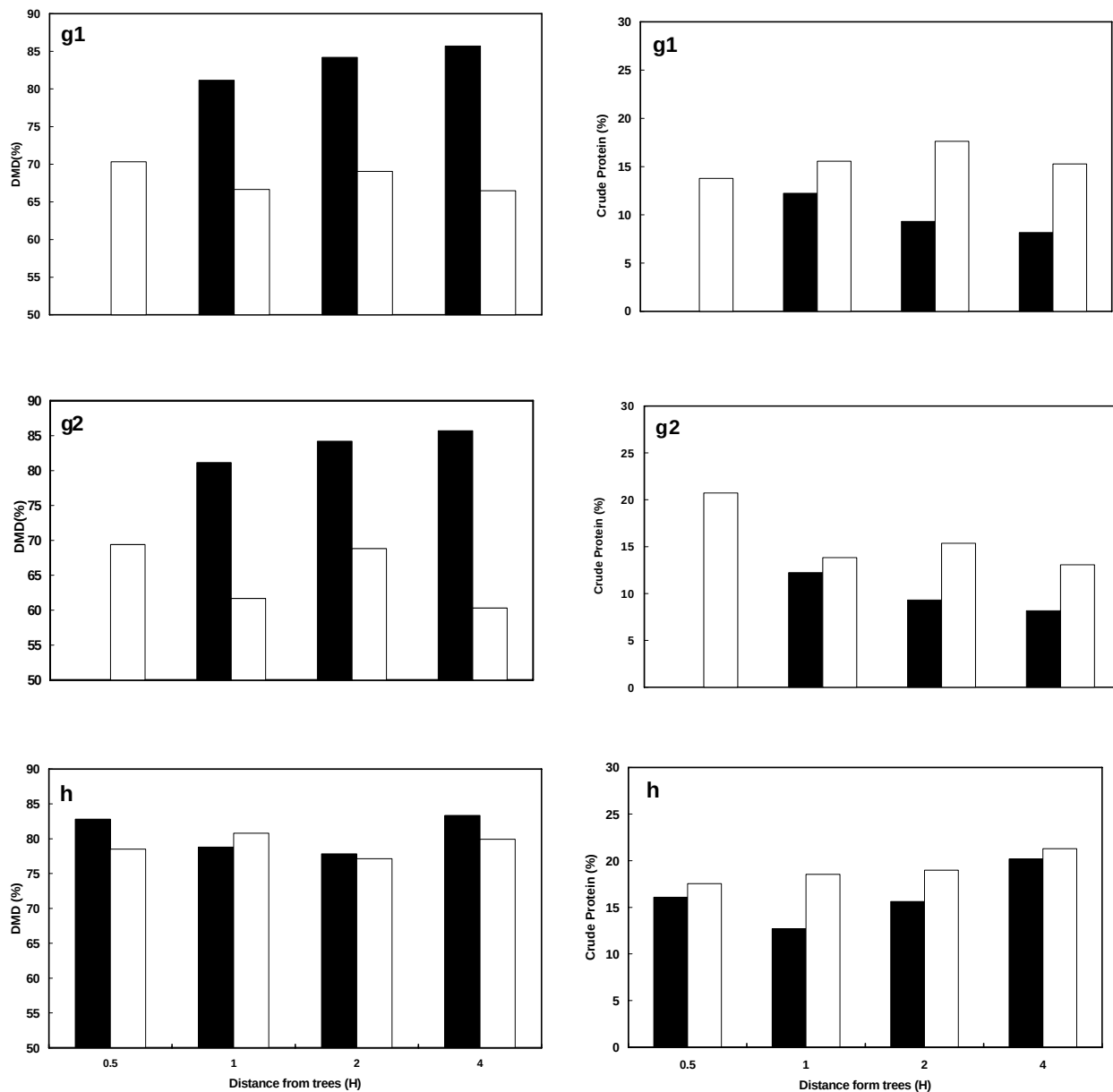


Figure 4 cont... Pasture dry matter digestibility (DMD) and crude protein for annual pasture (open bar) or perennial pasture (closed bar) at Site G kikuyu (g1), Site G consol lovegrass (g2) and Site H (h).

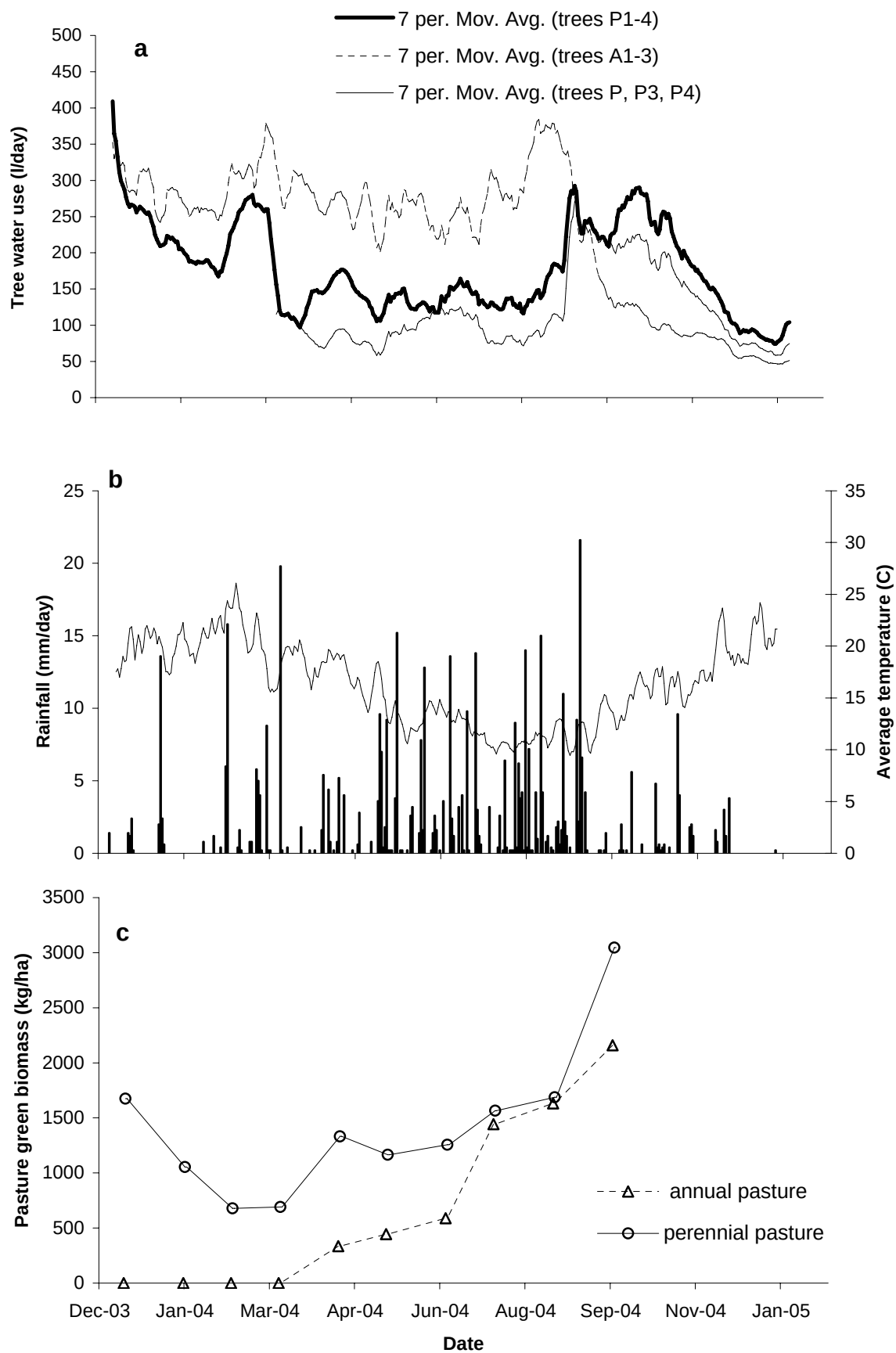


Figure 5. Mean water use for trees growing with an understorey of annual or kikuyu pasture (a), daily rainfall (bar) and average daily temperature (line) (b) and mean pasture green biomass between at 0.5 and 3.0 H (c). Note Figure (a) shows mean values for all trees growing with a kikuyu (P1-P4) or annual (A1-A3) and trees with kikuyu pasture that have similar diameters to the trees with annual pasture (P, P3, P4).

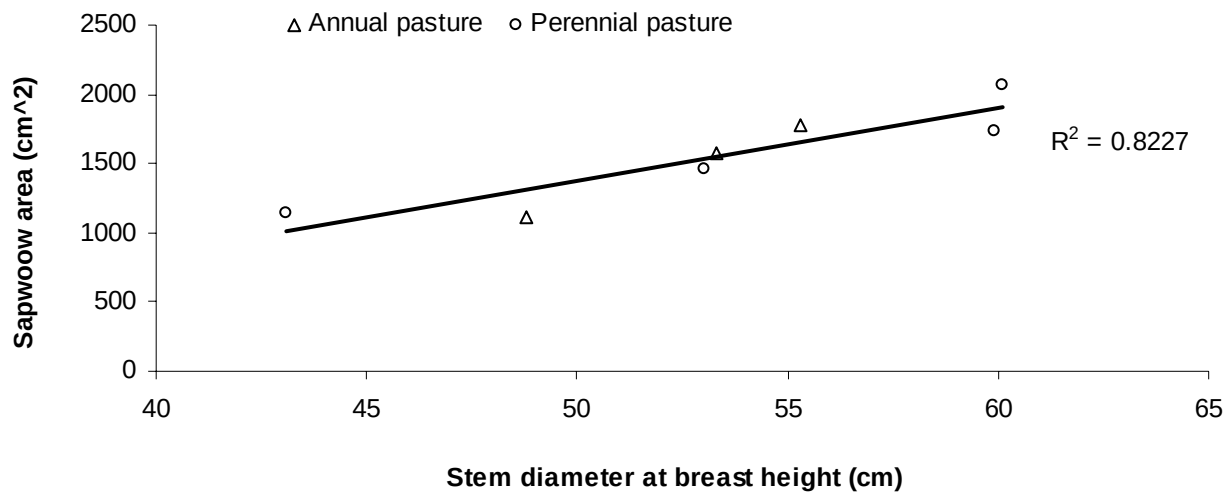


Figure 6. Relationship between stem diameter over bark at breast height and sapwood area for trees growing with annual or perennial pasture understorey, showing line of best fit for all data points.

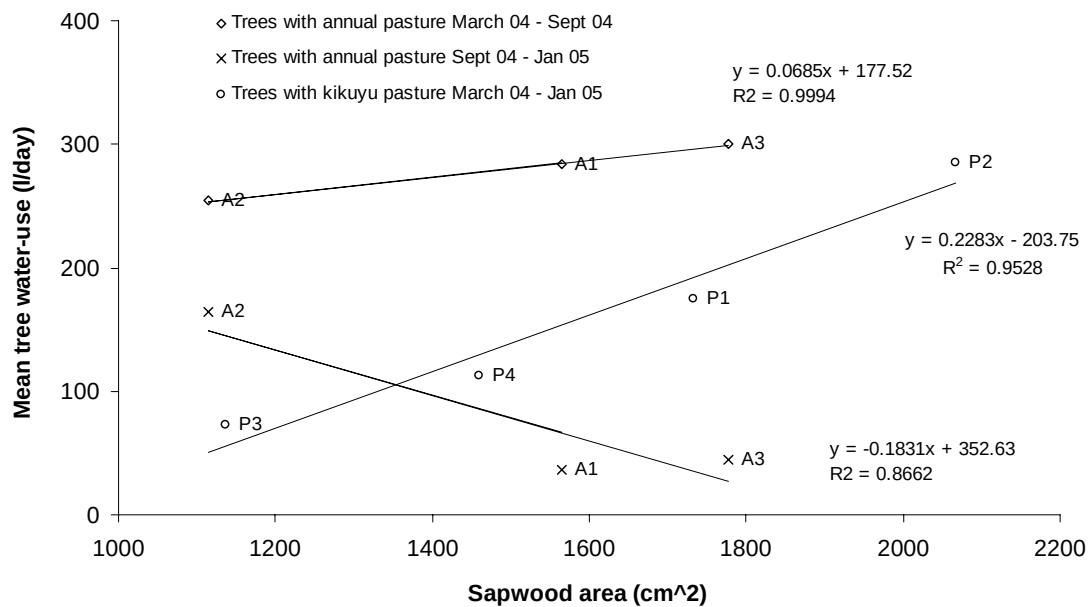


Figure 7. Relationship between sapwood area and mean sapwood velocity 15/3/04-1/9/04(a) 29/9/04-11/1/04 (b). Note: tree numbers, A = annual pasture and P = kikuyu pasture.

3.5 Roots

3.5.1 Tree root intercept density

It was possible to make comparisons between perennial and annual pasture treatments at Site H as the soil type, and particularly depth to clay, was relatively uniform within and between treatments, and the trees in each treatment were planted at the same time. However, at Sites D and G direct comparison between treatments was somewhat confounded by variable depth to clay at Site D and differences in tree age at Site G. That said, there were some general trends evident across all sites.

Across all sites and treatments, there was a general trend for tree root density to be greatest near the trees and to decline with distance from the trees (Figure 8). For trees with annual pasture, the greatest density of tree roots was in the sandy topsoil, particularly within the top 0.2 m and just above the clay, with a rapid decline in density in the subsoil clay. This trend was less evident under perennial pastures at Sites D and H as the density of tree roots in the sandy topsoil was greatly reduced compared to trees with annual pasture (Figure 8). The lateral extent of tree roots under annual pasture ranged between 2 H at Sites D and G and 2.5 H at Site H, and under perennial pasture ranged between 1.2 H at Site D (1.5 H at Site G) and 2.5 H at Site H.

3.5.2 Root length density

The root length density of Consol lovegrass at Site G and veldt grass at Site D increased with distance from the trees (Figures 9e and j). Total root length density (pasture and tree roots) also increased with distance from the trees at Site G but was generally lower near the trees with annual compared to perennial pasture (Figures 9f and g). The root length density of pine roots was less with perennial compared annual pasture at Sites D and G (Figures 9c, d and h and i).

3.5.3 Root biomass

At Site G, the root biomass of Consol lovegrass increased with distance from the trees while at Site H the root biomass of kikuyu was similar at all distances from the trees (Figure 10).

The distribution of tree root biomass in the sandy topsoil generally reflected differences in root intercept density. The exception was the distribution of tree root biomass for trees with perennial pastures at Site H, where there was a concentration of root biomass just above the subsoil clay due to the presence of a few large structural roots.

The estimated tree root biomass in the soil 0.25 - 1.25 H from the tree lines (one side only) ranged between 43.3 t/km (km of tree line) at Site H and 0.4 t/km at Site G (Table 9).

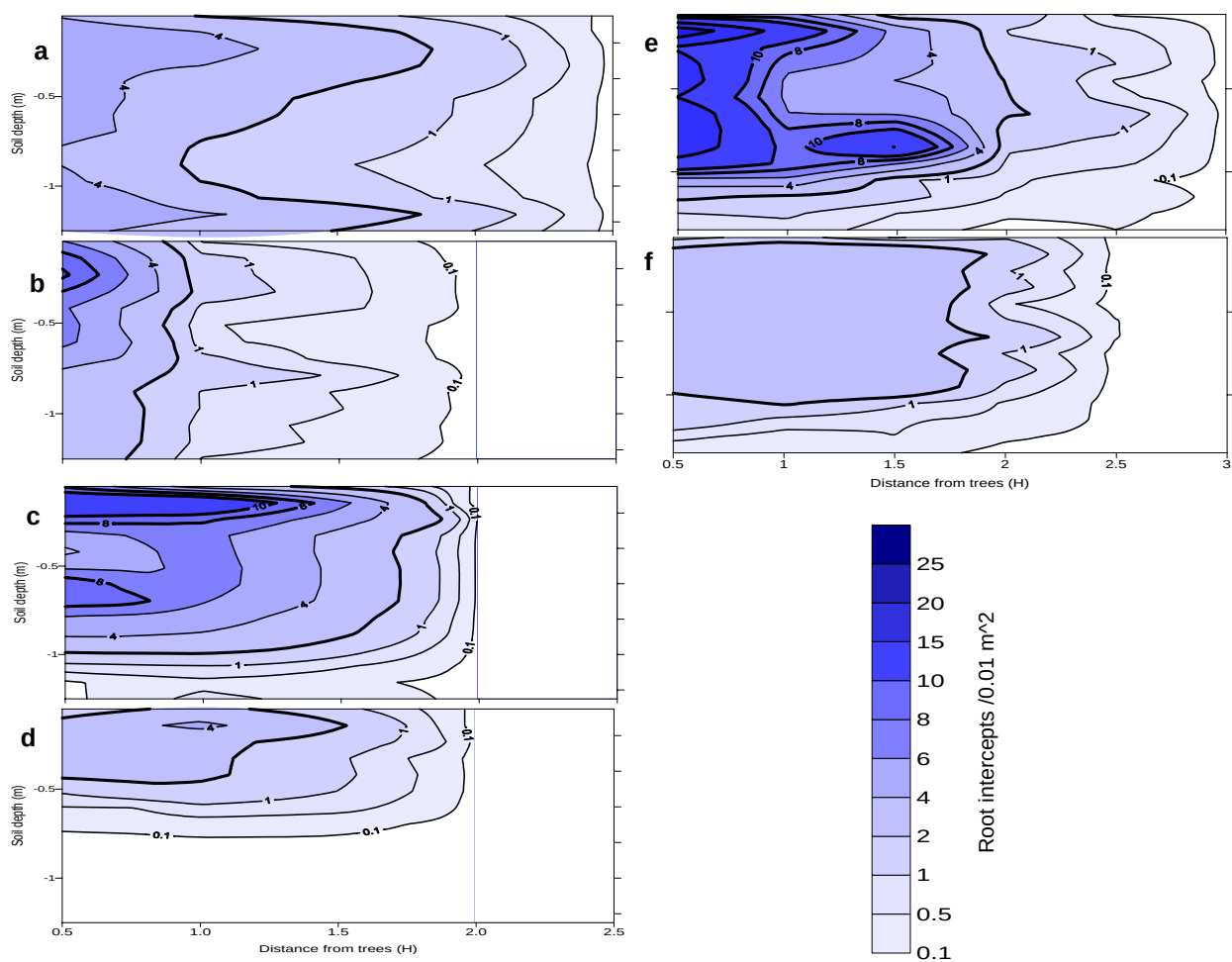


Figure 8. Root intercept density for *P. pinaster* at Site G with annual pasture (a) and perennial pasture (b), for *P. radiata* at Site D with annual pasture (c) and perennial pasture (d), and for *P. pinaster* at Site H with annual pasture (e) and perennial pasture (f). Figures drawn using triangulation with linear interpolation.

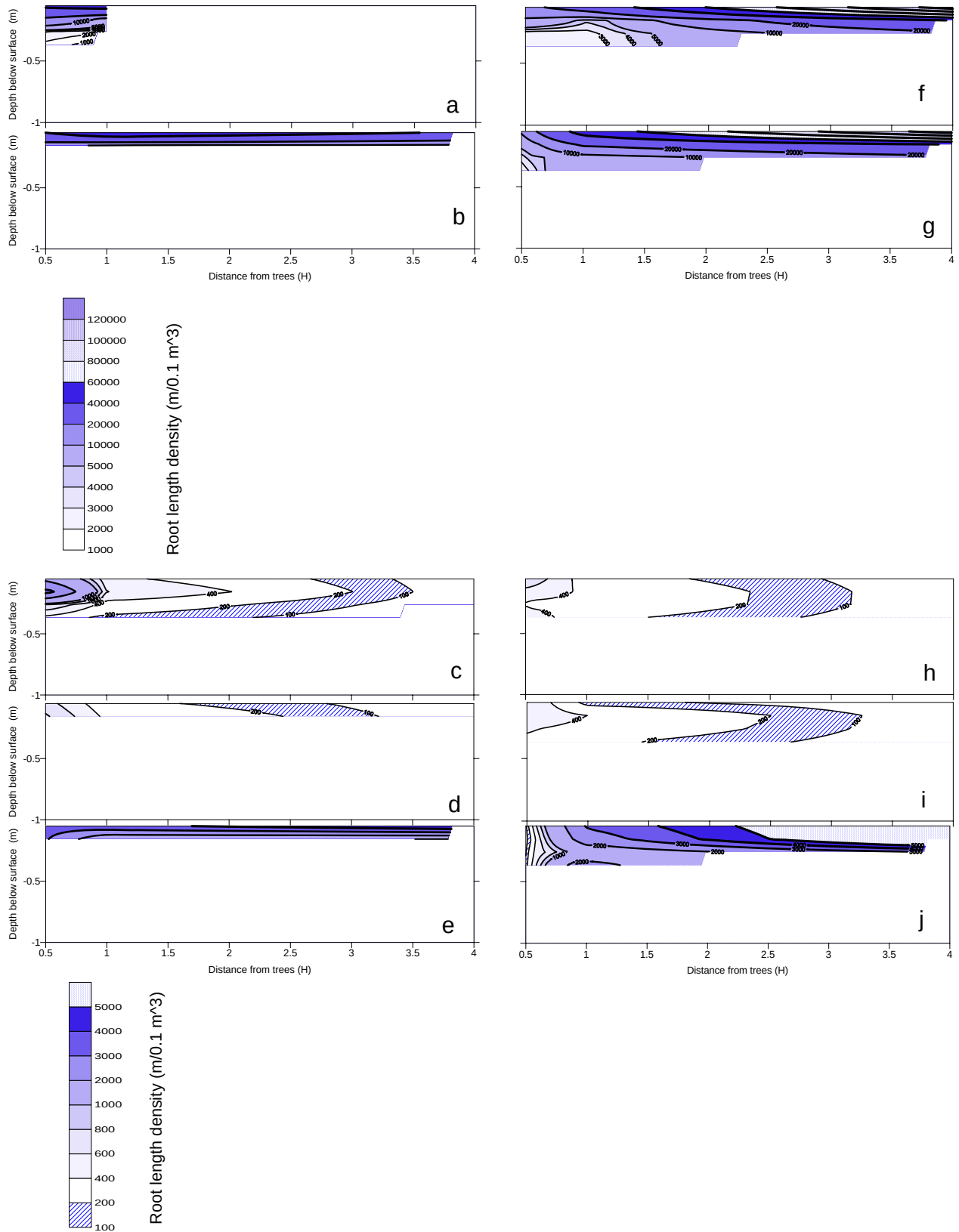


Figure 9. Root length density at Site D and Site G. Separate graphs are: Site D: Total roots including fine annual pasture roots for *P. radiata* with annual pasture(a) and *P. radiata* with perennial pasture (b), and *P. radiata* roots in annual pasture treatment (c), *P. radiata* roots in perennial pasture treatment (d) and perennial pasture roots (e). Site G: total roots including fine annual pasture roots for *P. pinaster* with annual pasture(f) and *P. pinaster* with perennial pasture (g), and *P. pinaster* roots in annual pasture treatment (h), *P. pinaster* roots in perennial pasture treatment (i) and perennial pasture roots (j). Figures drawn using triangulation with linear interpolation.

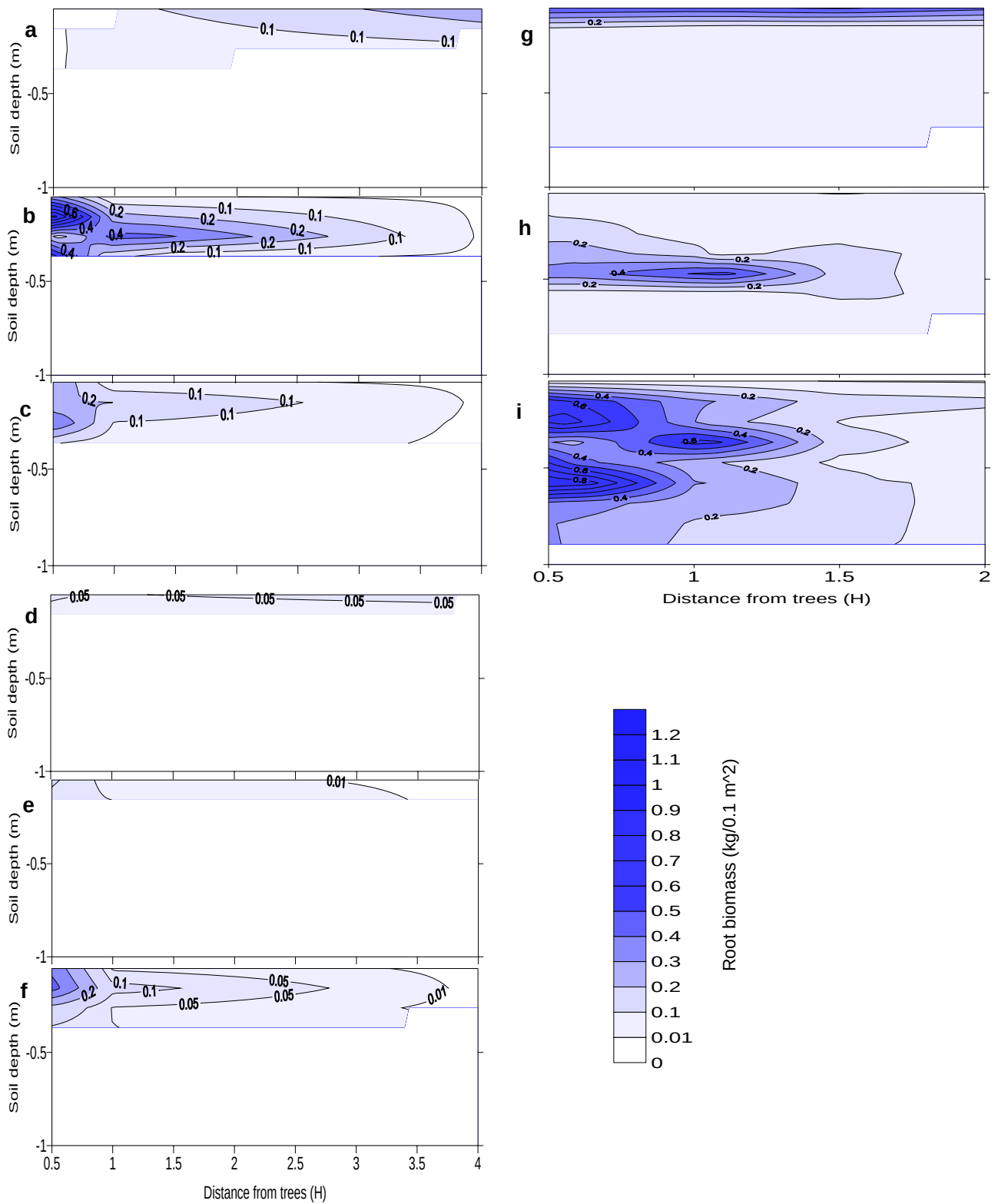


Figure 10. Root biomass at Site G, Site D and Site H. Separate graphs are: Site G root biomass of perennial pasture (a), *P. pinaster* with perennial pasture (b) and *P. pinaster* with annual pasture (c). Site D root biomass of perennial pasture (d), *P. pinaster* with perennial pasture (e) and *P. pinaster* with annual pasture (f) and at Site H of perennial pasture (g), *P. pinaster* with perennial pasture (h) and *P. pinaster* with annual pasture (i). Figures drawn using triangulation with linear interpolation.

Table 9. Estimated tree root biomass in the sandy topsoil between 0.25 and 1.25 H from the tree lines (one side only) at Sites D, G and H and between 0.25 and 2.25 H from the tree lines (one side only) at Site H. For trees with annual (PA) or perennial (PP) pastures.

Site	<i>Root wt (t/km of tree line)</i>					
	0.25-1.25 H			0.25-2.25 H		
	Tree roots PA	Tree roots PP	Perennial pasture roots	Tree roots PA	Tree roots PP	Perennial pasture roots
J	43.3	13.1	9.2	55.1	20.6	21.1
D	2.2	0.4	0.3			
G	5.4	12.8	1.1			

4. Discussion

The extent, density and biomass of tree roots in adjacent pasture in this study are similar to values reported at other sites on the south coast of Western Australia (Sudmeyer *et al.*, 2004), with tree roots extending laterally 1.5 to 2.5 H under annual crops and pastures. This investigation has shown that competition between trees and pastures resulted in consistently reduced annual pasture yield within the tree root zone, by up to 53% on average.

This confirms the results of a number of studies undertaken in southern Australia that have observed lower yields from annual crops and pastures within the root zone of windbreaks or tree belts (Bicknell, 1991; Burke, 1991; Lefroy and Stirzaker, 1999; Bird *et al.*, 2002; Knight *et al.*, 2002; Nuberg *et al.*, 2002; Sudmeyer *et al.*, 2002; Woodall and Ward, 2002; Sanford *et al.*, 2003). The reduction in plant growth has been attributed to competition between trees and pasture for soil moisture, nutrients and light (Nuberg 1998; Bird 1998; Schroth 1999). There was no strong evidence in this investigation that the reduction can be attributed to competition for nutrients.

Other studies in Western Australia have also shown that soil nutrient concentrations and annual crop nutrition are largely similar inside and outside the tree root zone along tree lines (Sudmeyer and Scott, 2002; Sudmeyer *et al.*, 2004). However, soil water content was less in the tree root zone compared to under sole annual pasture at two sites in this study, again confirming other studies in southern Australia showing reduced soil water content adjacent to tree lines and suggesting that the principle mechanism reducing annual plant growth in the tree root zone is competition for water (Hall *et al.*, 2002; Knight *et al.*, 2002; Woodall and Ward, 2002; Sudmeyer *et al.*, 2004).

In contrast to annual pasture, the decline in perennial grass pasture yield within the tree root zone was at most 10% on average. Furthermore, in comparison to the open annual pasture yield, perennial grass yield was similar or greater even within 0.5 H of the tree belt, suggesting perennial grasses are more successful in competing with trees for moisture, or were less affected by periodic moisture stress. The displacement of *P. pinaster* roots from the upper 1.5 m of the soil profile by perennial grasses in this study would tend to confirm the former suggestion at least. While consol lovegrass at Site D was sown when the pines were planted, kikuyu at sites G and H was sown next to mature pines suggesting they can out-compete the trees. These results confirm the finding of Sanford *et al.* (2003) in the high rainfall zone that kikuyu growth is not reduced by tree competition. This study however, also demonstrates that tall wheat grass, veldt grass, Rhodes grass and consol lovegrass are similarly competitive with trees in medium rainfall environments.

Schroth (1999) concluded that perennial forage species were generally more competitive with trees in comparison with annual crops and pasture because of their deeper and denser root systems. That does not appear to be the case for lucerne in this study where yields were reduced by tree competition, on average up to 63%. This may have been due to poor establishment when they were sown into the dry soil alongside established trees. Soil measurements also suggest that the reduced availability of phosphorus in close proximity to trees may have limited subsequent lucerne growth. Interestingly, Chang and Mead. (2003) found lucerne to be most competitive with *P. radiata* when compared with of a suite of perennial pasture species. It should be noted that in Chang and Mead's (2003) study the pastures and trees were established at the same time, and that the competitiveness of lucerne declined relative to the grass species over time.

While other studies have shown differences in shade tolerance among pasture species (Wilson, 1996; Lin *et al.*, 2001; Silva-Pando *et al.*, 2002), it is unclear to what extent shade influenced pasture response in this study.

It is difficult to draw any conclusions about the impact of tree competition on pasture nutritive value however the overall results support the unpublished findings of Sanford *et al.* (2003) that changes are small. It is interesting that at four of the 21 sites, pasture yield was greater at both 1 H and 2 H in compared to 4H suggesting increased growth as a consequence of favourable changes in microclimate

(e.g. improved warmth and humidity; Cleugh 1998) or soil nutrient process (East and Felker, 1993; Wilson, 1996).

Seasonal patterns of *P. pinaster* transpiration measured at Site H were typical of trees growing in Mediterranean environments (Farrington *et al.*, 1994; Schiller and Cohen, 1995), that is, peak transpiration rates occurred when rainfall coincided with warmer conditions. In the absence of summer rainfall, this was during spring and autumn. Additionally, trees growing with annual or perennial pasture understorey at Site H had differing transpiration rates, and slightly differing seasonal patterns of water-use.

Between December 2003 and September 2004, *P. pinaster* with a kikuyu understorey generally transpired less water compared to trees with an annual pasture understorey. While the water-use of kikuyu wasn't measured, it is reasonable to assume that this is due to competition between the pines and kikuyu. Measurement showed tree roots were displaced from the upper 1.8 m of the soil profile by kikuyu roots and the kikuyu pasture remained green throughout the year compared to annual pasture which was only green during winter and spring. However it is not clear why this trend was reversed in late August 2004 when the water-use of pines with annual pasture understorey declined sharply while the water use of pines with perennial pasture increased following 44 mm of rainfall. Interestingly, while there was greater green biomass in the perennial pasture compared to the annual pasture, pasture production was greater from the annual pasture than the perennial pasture at this site. Clearly further investigation is required to determine if differing tree water-use patterns reflects differing times of peak water-use (and hence competition) by annual and kikuyu pasture so that the combined water-use of the trees and pastures peaked and depleted stored soil moisture at differing times, or the extraction of soil water from deeper in the profile by pines with kikuyu understorey, or some other mechanism.

While pines with a kikuyu understorey used less water than pines with annual pasture, other studies suggest that the additional water used by the perennial pasture would more than offset reduced tree water use (McDowell *et al.*, 2003; Sanford *et al.* 2003). Indeed, measurements of soil water content at Sites G and H showed perennial pastures outside the tree root zone appeared to dry the soil to similar water contents as trees and annual pasture within 2 H. Consequently, at a paddock scale, perennial pasture based agroforestry systems would be more effective than annual pasture based systems in reducing groundwater recharge.

Reduced tree root density and extent, and reduced transpiration from pines with kikuyu pasture compared to annual pasture implies reduced access to resources and less opportunity for photosynthesis, and hence growth. Indeed it is accepted silvicultural practice that reducing competition from weeds improves tree survival and growth (Cremer *et al.*, 1984, Fagg, and Cremer, 1990, Maclaren, 1993). Tree growth was not measured during this one year study, but at the 70% of sites where pasture biomass production in the root zone of trees was greater for perennial pasture than annual pasture it is safe to assume that the perennial pasture was providing more competition with the trees for resources, and so may have been reducing tree growth. If so, this will have economic implications where trees are being grown to produce commercial products but is of less importance if trees have been planted for shelter, aesthetic or landcare benefits.

It has been suggested that the improved growth of trees in silvopastoral systems with improved pastures is due to greater soil fertility and less competition compared to trees growing in plantations or native forests (Moore, 1991; Ares *et al.*, 2003). However, highly competitive perennial pasture species in agroforestry systems can reduce tree growth significantly (Chang and Mead, 2003). The success of silvopastoral systems relies on a good understanding of the relative profitability and cash-flow of the timber and livestock components and how they interact (Kellas *et al.*, 1995; Malajczuk *et al.*, 1996). Further work is required to determine if commercial trees growing in silvopastoral systems with perennial pasture will have acceptable growth rates in the Western Australian environment.

5. Implications

1. Perennial grasses that are drought tolerant and adapted to low fertility (eg. kikuyu, tall wheat grass, Rhodes grass, veldt grass and consol lovegrass) are better able to compete with trees than annual pastures and lucerne in the high to medium rainfall zone of southwest Australia.
2. Other than the area directly under the tree crown, agroforestry systems that include perennial grasses will produce at least similar amounts of forage to annual pastures alone.
3. Lucerne competes poorly with trees, however pasture losses may be overcome by maintaining soil available P and establishing the trees and lucerne in the same growing season. This requires further investigation.
4. Perennial pastures affect tree rooting patterns and water use. Presumably decreased water use will equate to reduced photosynthesis and hence tree growth.
5. It is likely that there will be less leakage under perennial pasture based agroforestry systems compared to annual based systems.
6. If the trees and pasture are established concurrently what are the implications for early tree and pasture growth?
7. What are the economic implications of perennial vs. annual pasture systems in alley or wide spaced agroforestry systems?
8. How do the interactions between trees and perennial pastures affect the timing of tree/pasture water use and where in the soil profile the trees access water from?

6. Recommendations

1. The design of agroforestry systems in the south west of Australia should include drought tolerant perennial grasses if the objective is to minimise losses of forage production. Species proven to date include kikuyu, tall wheat grass, veldt grass (though there is limited seed available), Rhodes grass and consol lovegrass. It is likely that setaria, panic, digit grass and native grasses would also be competitive with trees.
2. Further research is required to determine the effect perennial pasture species have on the growth of commercial tree species in silvopastoral systems across a range of environments. These data should be used to assess the economics of various silvopastoral systems in a range of environments.
3. Further research is required to determine the best methodologies for establishing and managing perennial pastures in existing and new agroforestry systems.

7. Appendices

7.1 Soil Chemistry

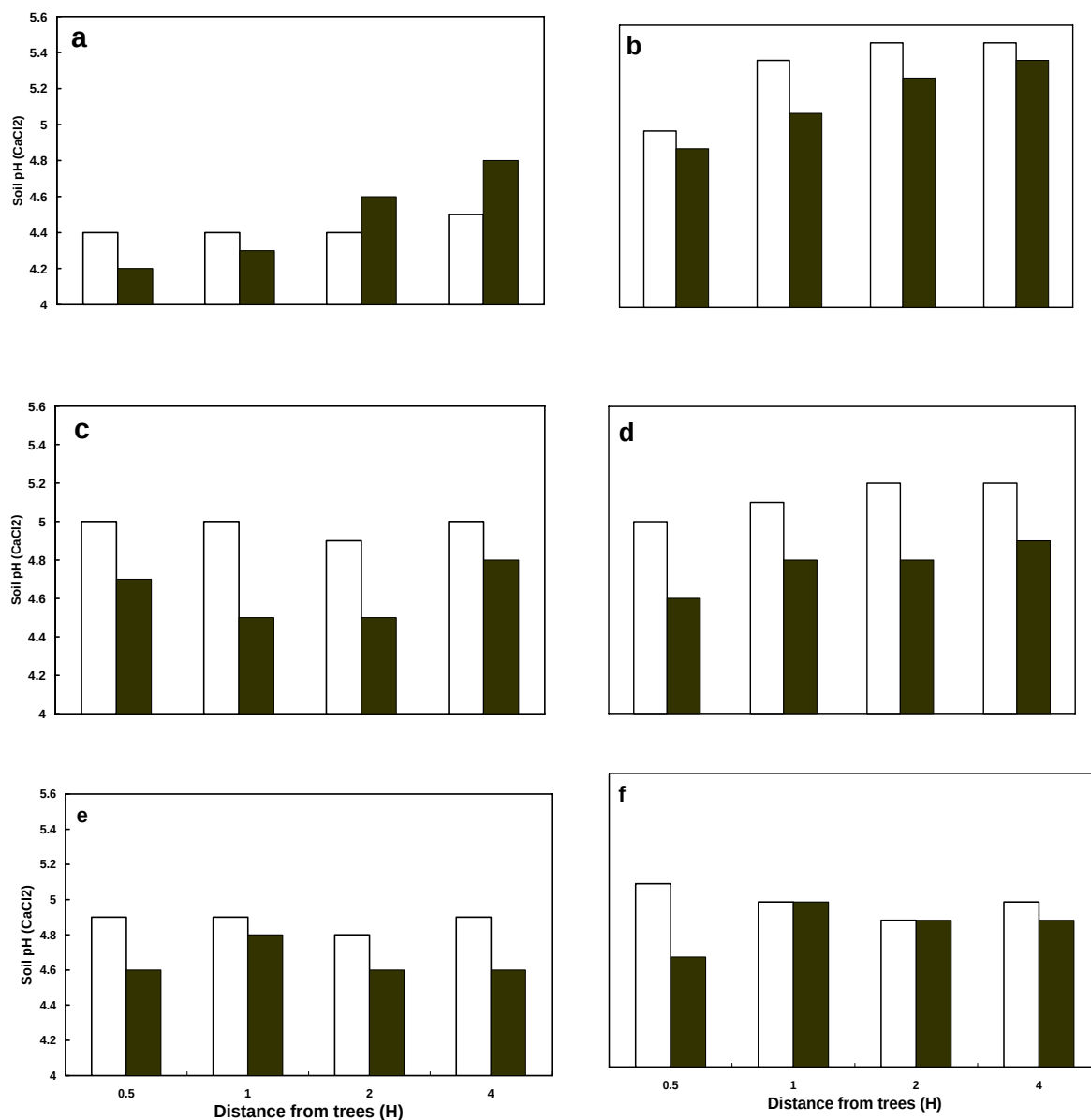


Figure 11. Soil pH (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/2004, at Site A (a), Site B (b), Site C (c), Site D (d), Site E (e), Site F (f).

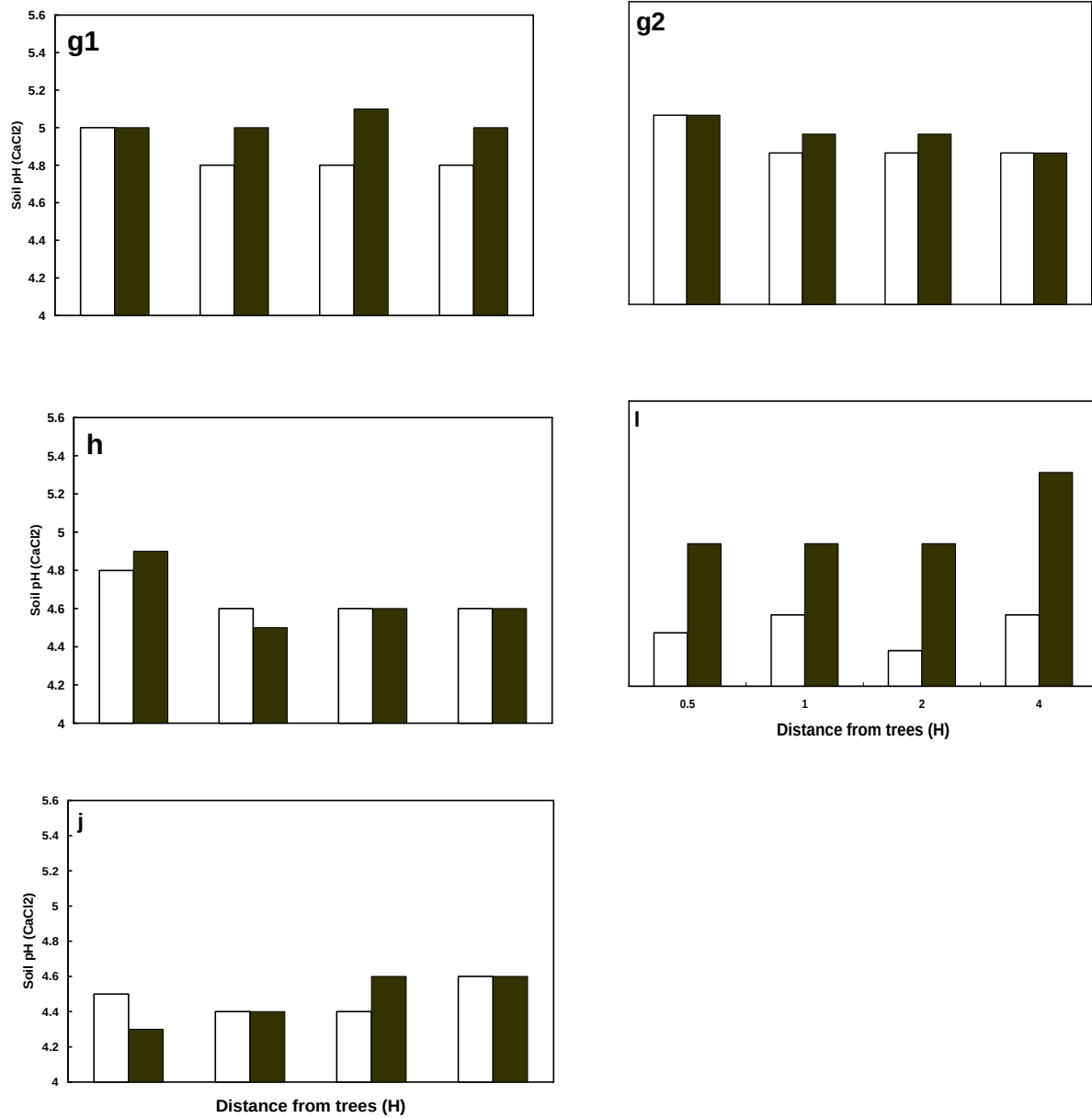


Figure 11 cont. Soil pH (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/2004 at Site G kikuyu (g1), Site G consol lovegrass (g2), Site H (h), Site I (i), and Site J (j).

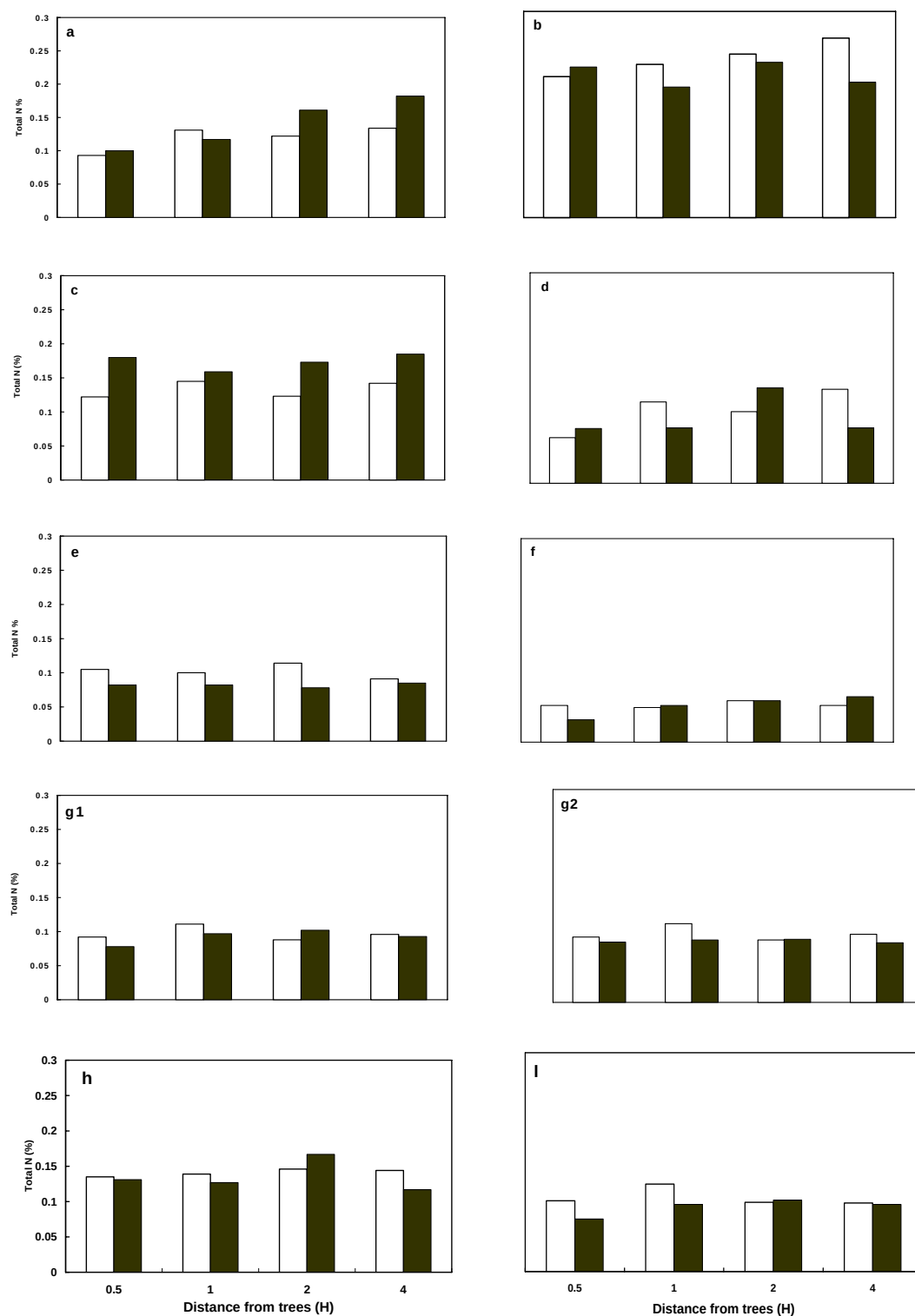


Figure 12. Soil total N (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/2004. At Site A (a), Site B (b), Site C (c), Site D (d), Site E (e), Site F (f), Site G kikuyu (g1), Site G consol lovegrass (g2), Site H (h), Site I (i).

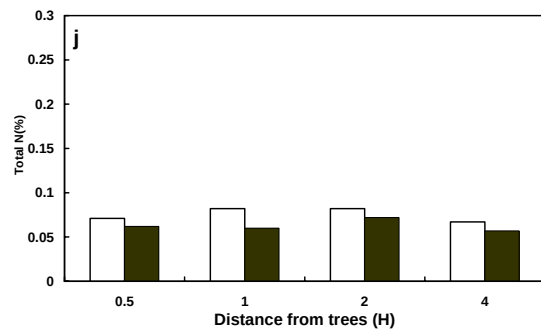


Figure 12 cont... Soil total N (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/2004. At Site J (j).

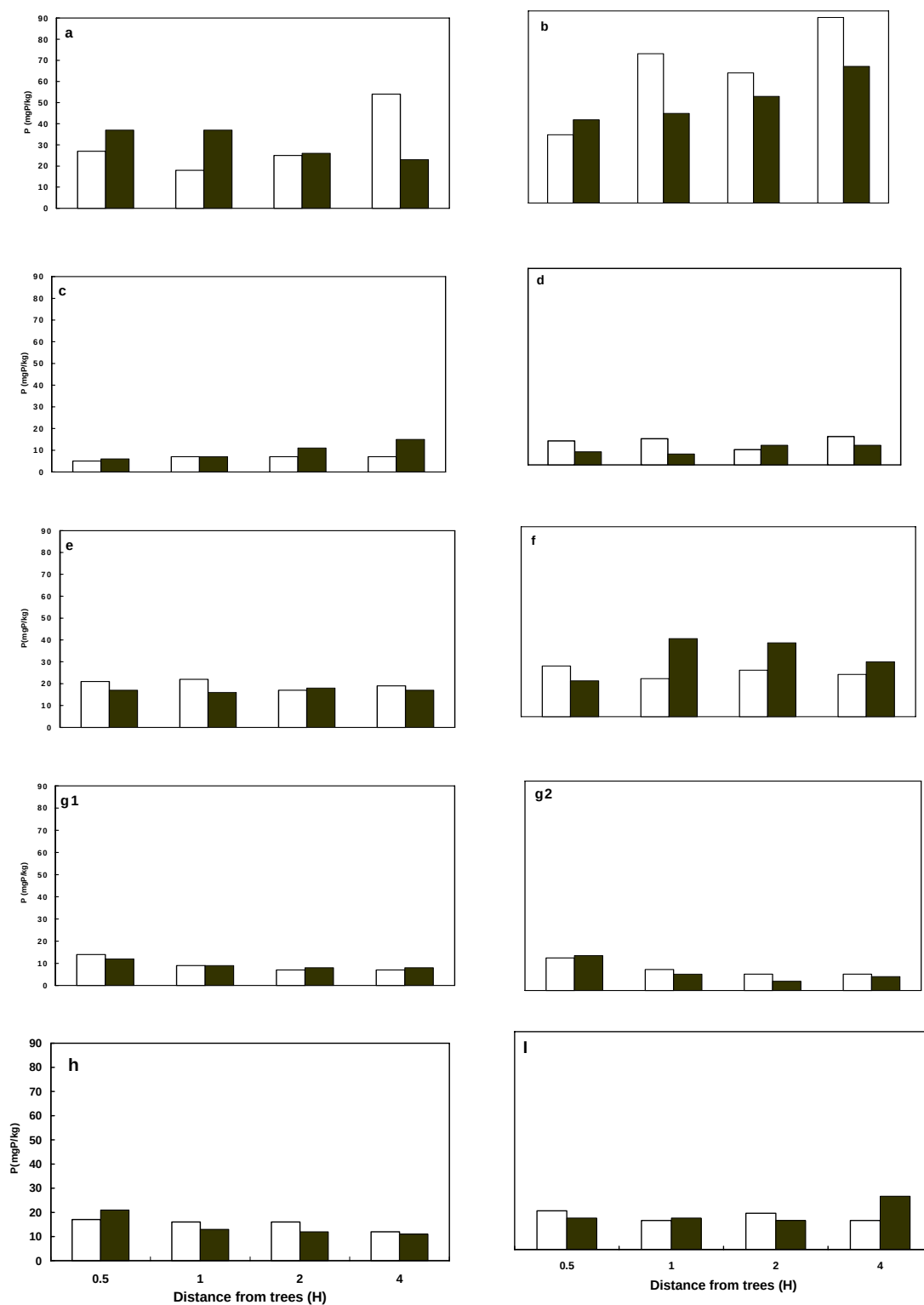


Figure 13. Soil available P (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/2004. At Site A (a), Site B (b), Site C (c), Site D (d), Site E (e), Site F (f), Site G kikuyu (g1), Site G consol lovegrass (g2), Site H (h), Site I (i).

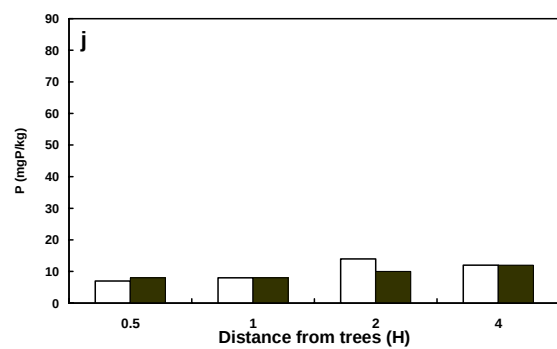


Figure 13 cont... Soil available K (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/04. At Site J (j).

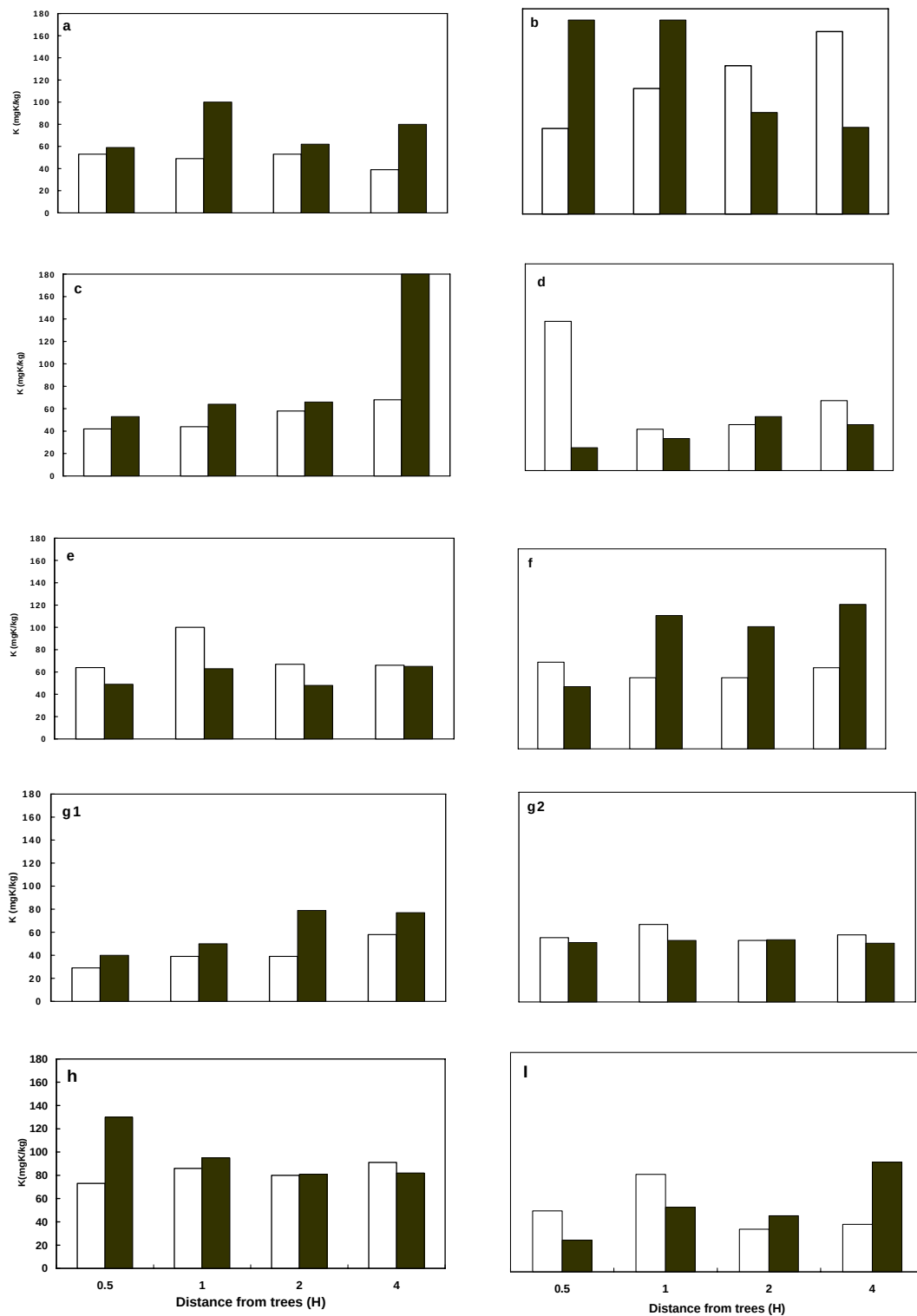


Figure 14. Soil available K (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/04. At Site A (a), Site B (b), Site C (c), Site D (d), Site E (e), Site F (f), Site G kikuyu (g1), Site G consol lovegrass (g2), Site H (h), Site I (i).

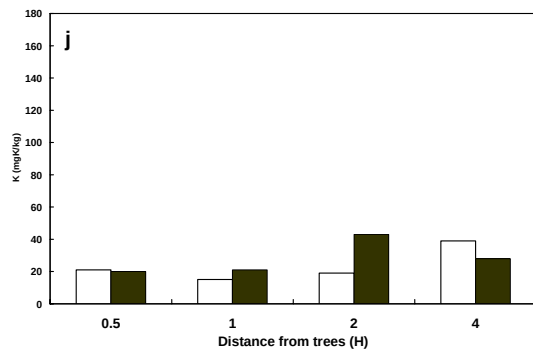


Figure14 cont... Soil available K (0-0.10 m) at various distances in tree heights (H) into adjoining annual (open bar) or perennial (solid bar) pasture for sites surveyed in 2003/04. At Site J (j).

7.2 Pasture botanical composition

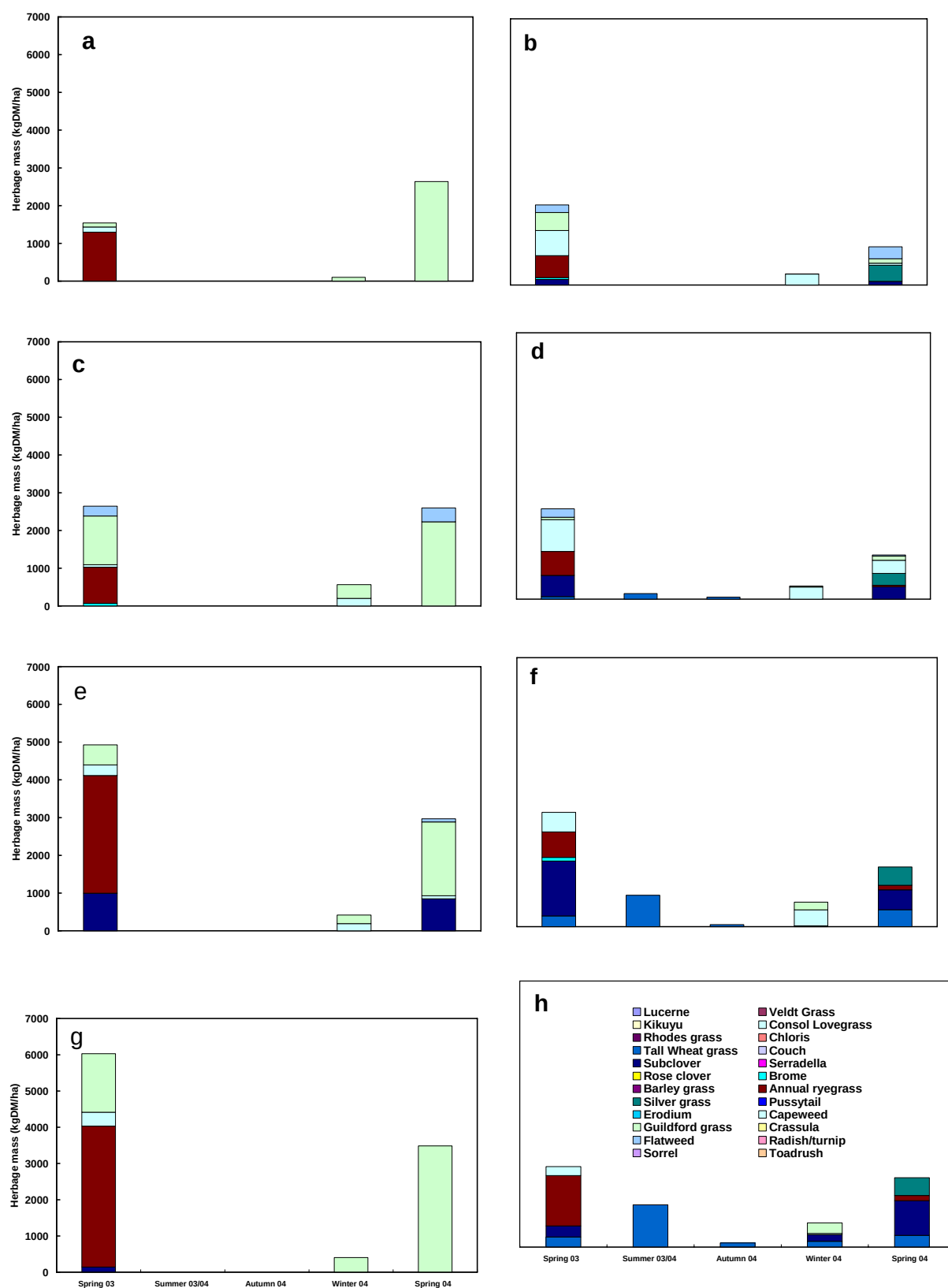


Figure 15. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site A throughout 2003/04. Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show flatweed (*Hypochaeris*), Guildford grass (*Romulea*), capeweed (*Arctotheca calendula*), annual ryegrass (*Lolium rigidum*), brome (*Bromus diandras*) and subclover (*Trifolium subterraneum*). Figures b, d, f, h show flatweed, guildford grass, capeweed, silver grass (*Vulpia myuros*), annual ryegrass, brome, subclover and tall wheat grass (*Thinopyrum elongatum*).

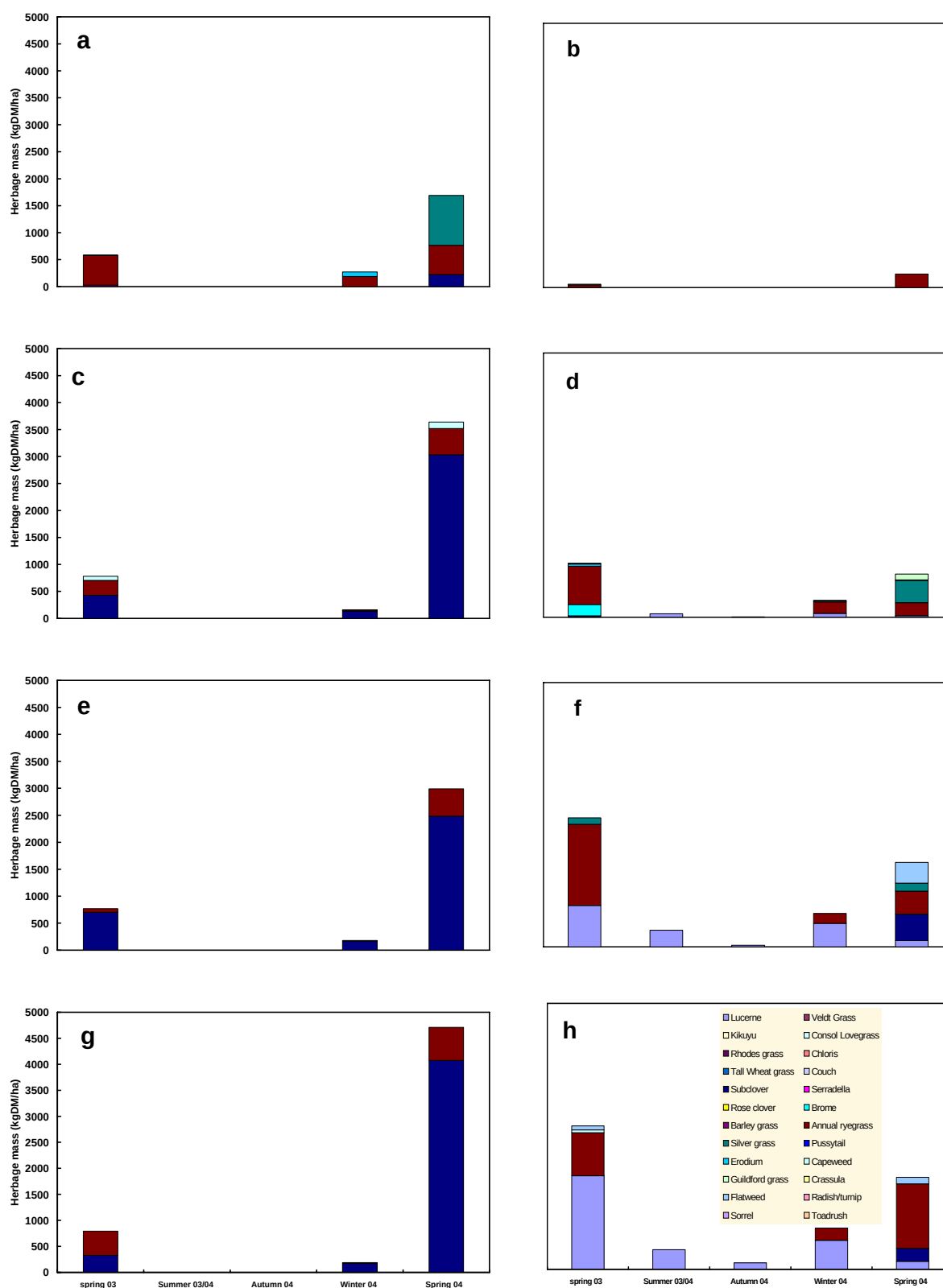


Figure 16. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site B throughout 2003/04. Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g shows flatweed, guildford grass, capeweed, annual ryegrass, brome, subclover, barley grass (*Horedeum leporinum*), erodium (*erodium botrys*) and silver grass. Figures b, d, f, h show flatweed, guildford grass, capeweed, silver grass, annual ryegrass, brome, subclover, lucerne (*Medicago sativa*) and erodium.

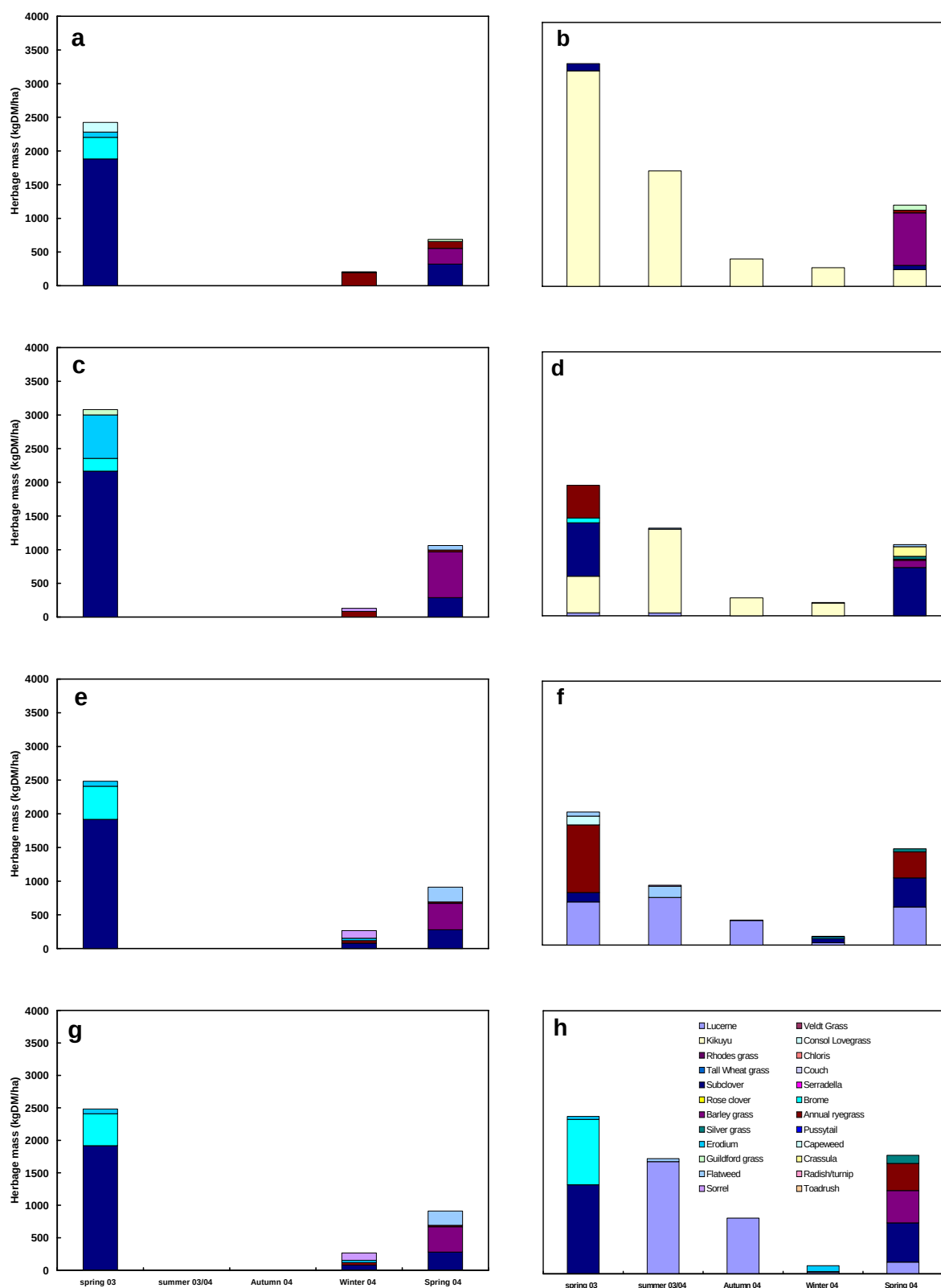


Figure 17. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site C throughout 2003/04. Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (g). Figures a, c, e, g, show flatweed, Guildford grass, erodium, annual ryegrass, barley grass, brome and subclover. Figures b, d, f, g show sorrel (*Rumex acetosella*), flatweed, crassula (*Colorata*), guildford grass, capeweed, erodium, silver grass, annual ryegrass, barley grass, brome, subclover, kikuyu (*Pennisetum clandestinum*) and lucerne.

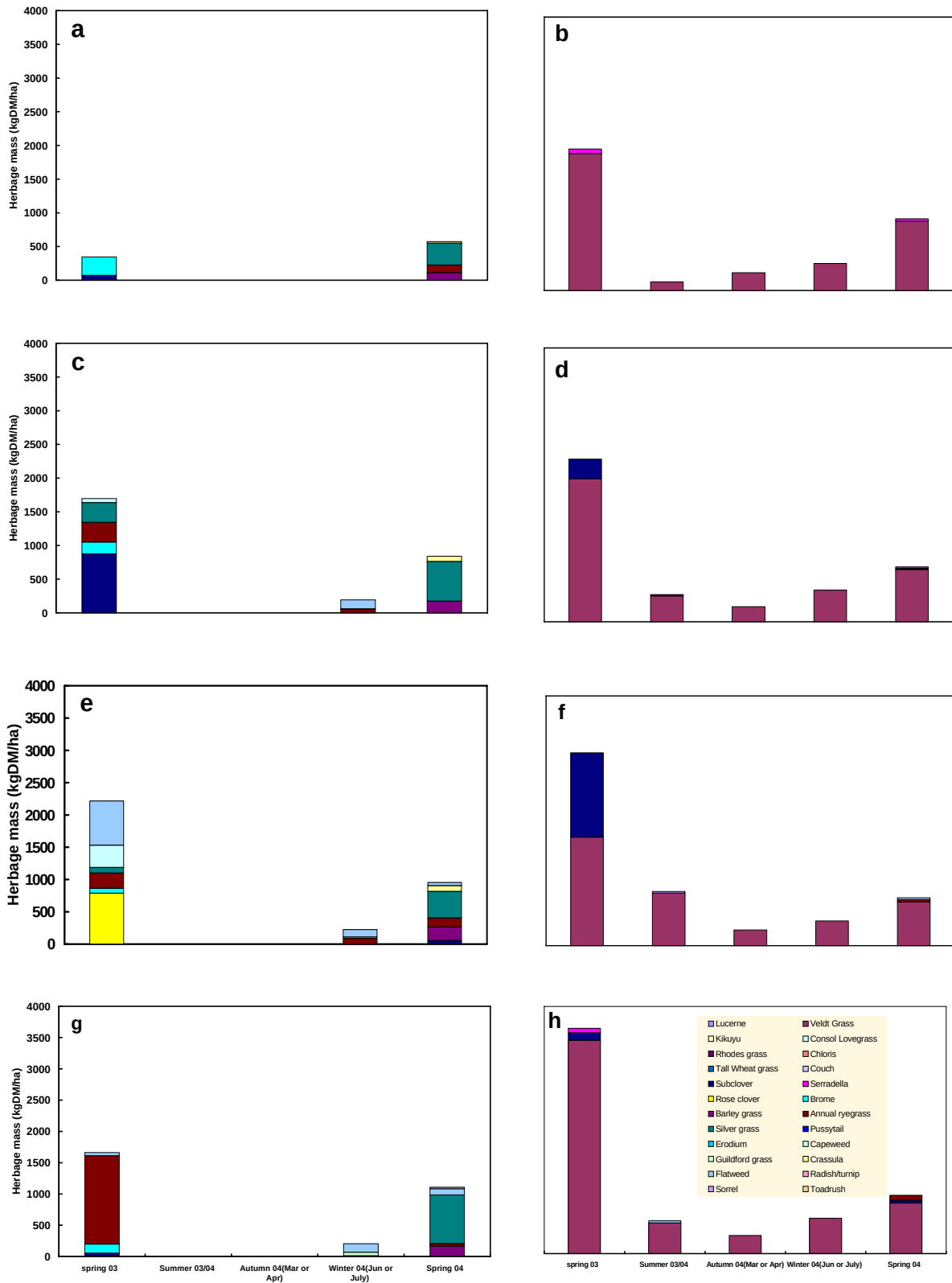


Figure 18. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site D throughout 2003/04. Legend: Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show sorrel, flatweed, crassula, guildford grass, capeweed, silver grass, annual ryegrass, barley grass, brome, rose clover (*Trifolium hirtum*) and subclover. Figures b, d, f, h, show flatweed, annual ryegrass, serradella (*Ornithopus*), subclover, Rhodes grass (*Chloris gayana*) and veldt grass (*Ehrarta calycina*).

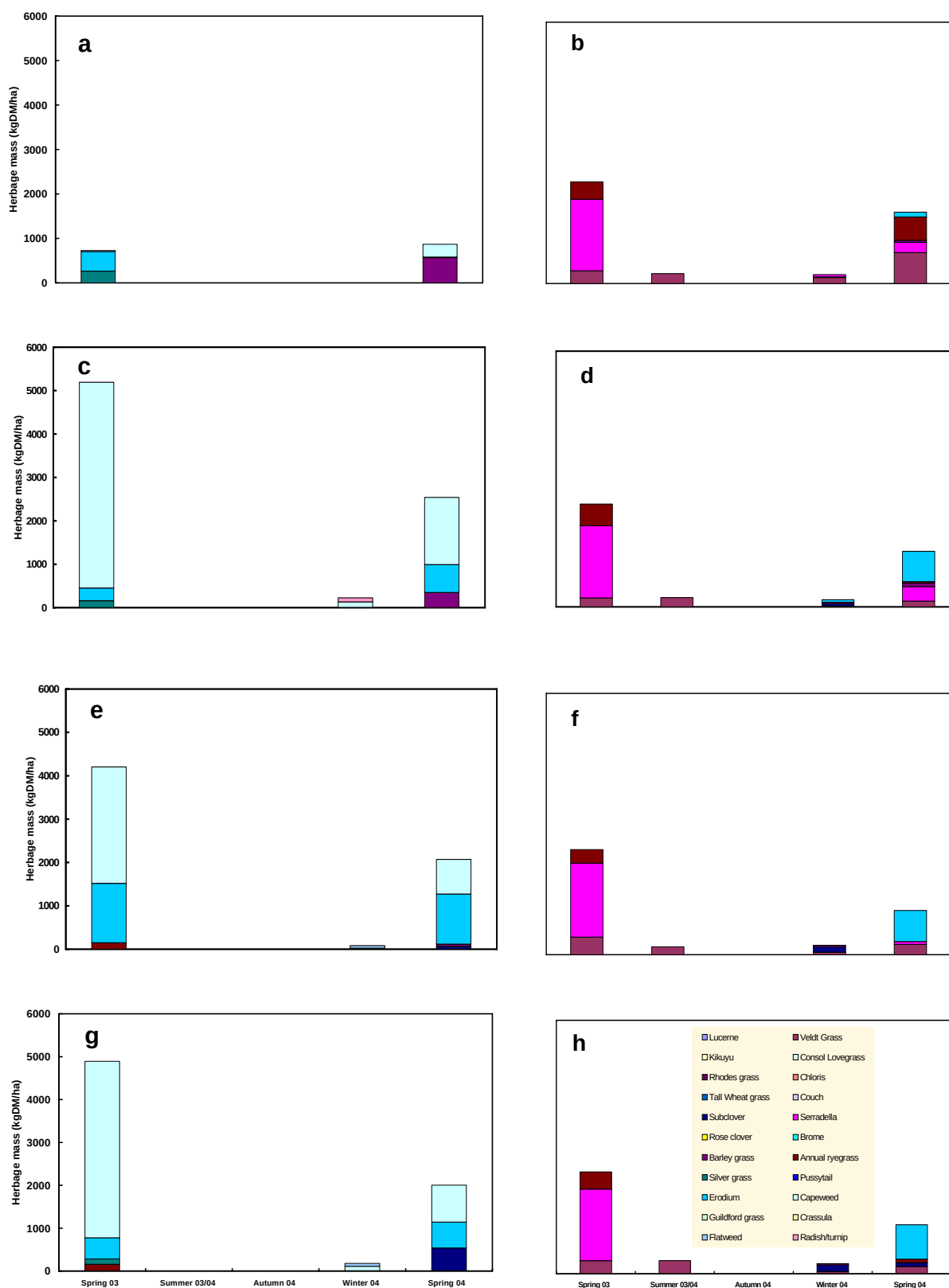


Figure 19. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site E throughout 2003/04. Annual – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show radish/turnip (*Rapistrum rugosum*), flatweed, capeweed, erodium, silver grass, annual ryegrass, barley grass, brome and subclover. Figures b, d, f, h, show erodium, annual ryegrass, barley grass, serradella, subclover and veldt grass.

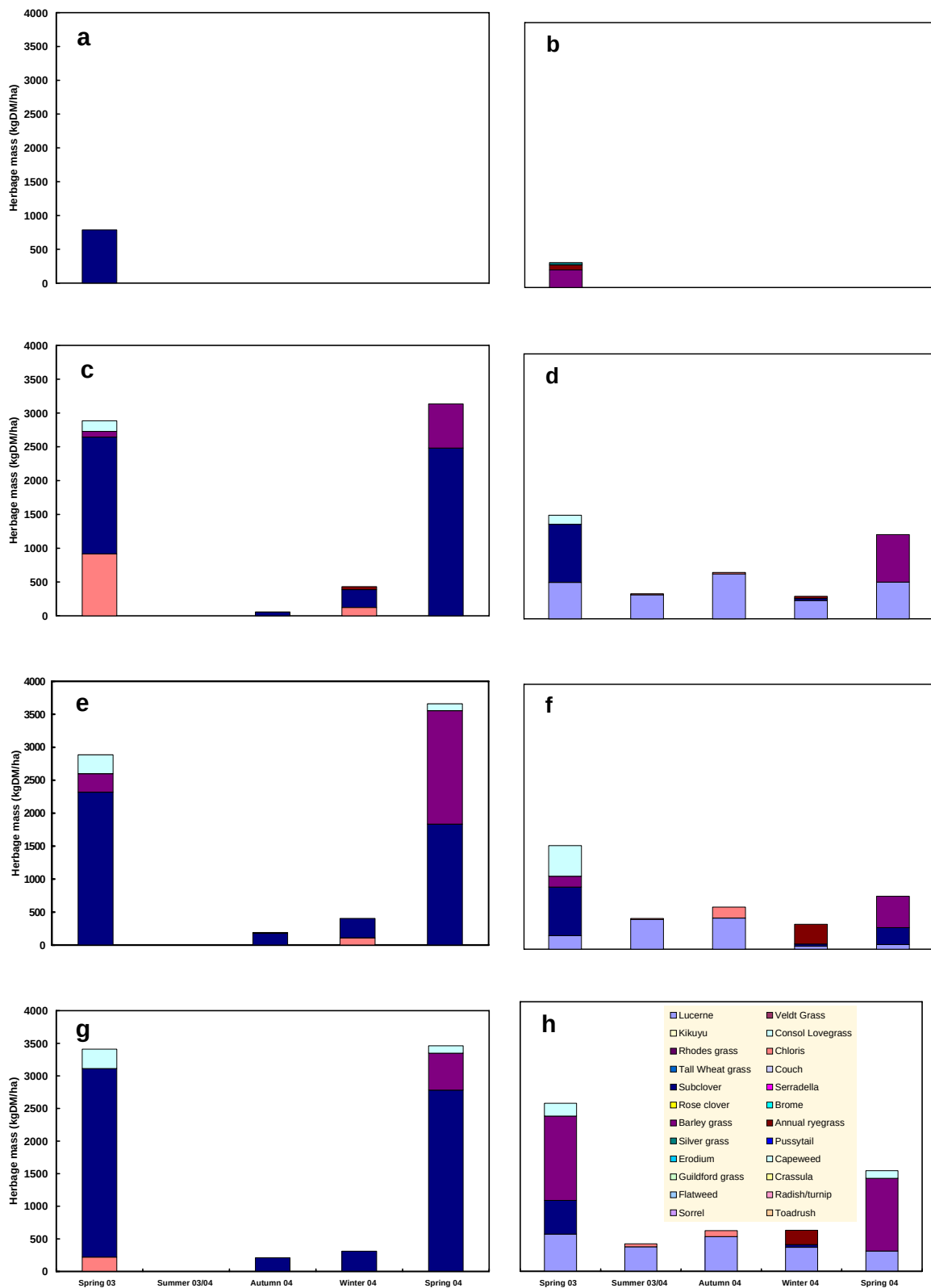


Figure 20. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site F throughout 2003/04. Annual – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g, show mintweed (*Chenopodium pumilio*), capeweed, annual ryegrass, barley grass, subclover and chloris. Figures b, d, f, h show capeweed, annual ryegrass, barley grass, subclover, chloris (*Chloris virgata*) and lucerne.

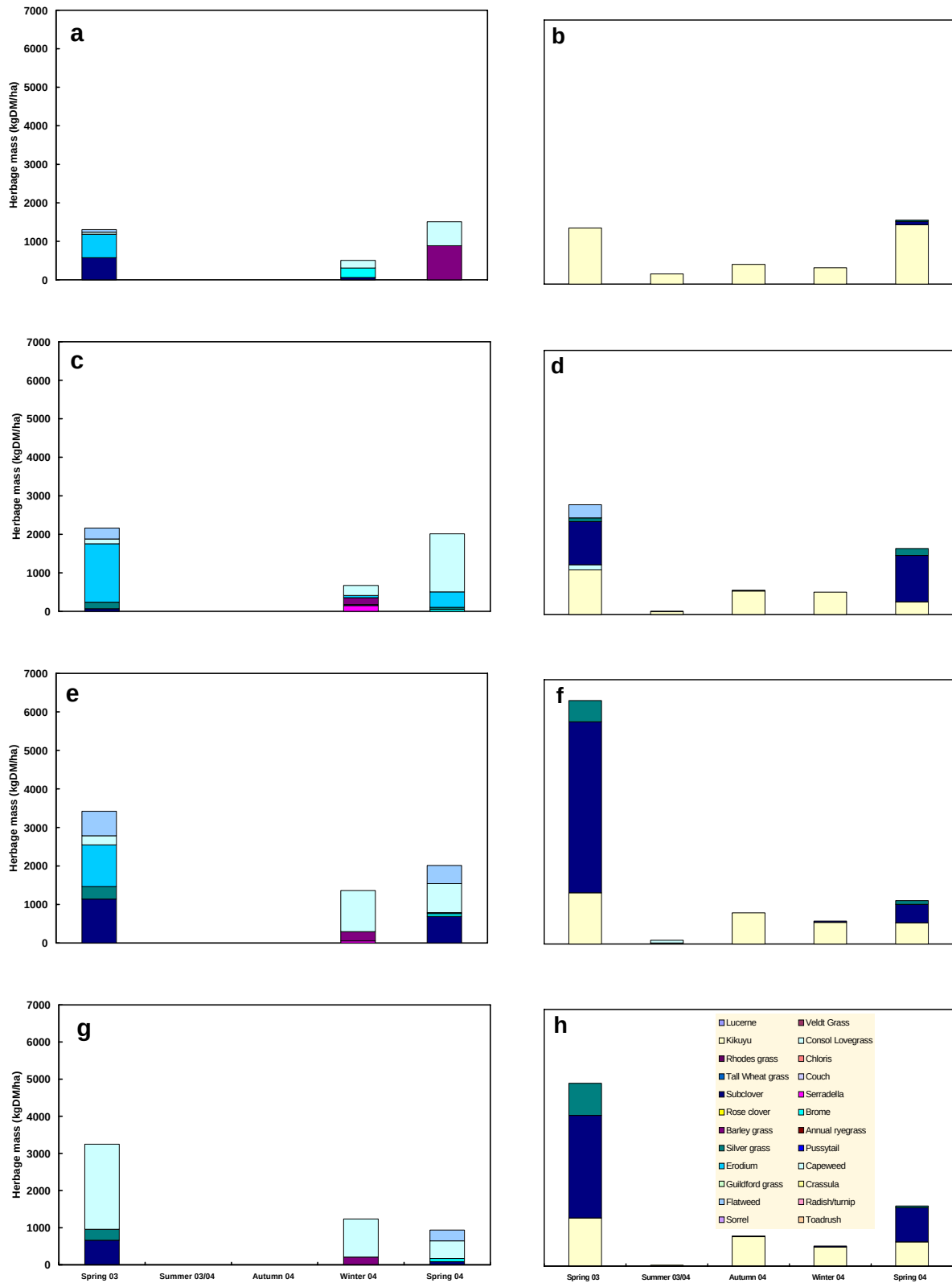


Figure 21. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site G Kikuyu throughout 2003/04. Annual – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show flatweed, capeweed, erodium, silver grass, barley grass, brome, serradella and subclover. Figures b, d, f, h show flatweed, silver grass, subclover, consol lovegrass (*Eragrostis curvula*) and kikuyu.

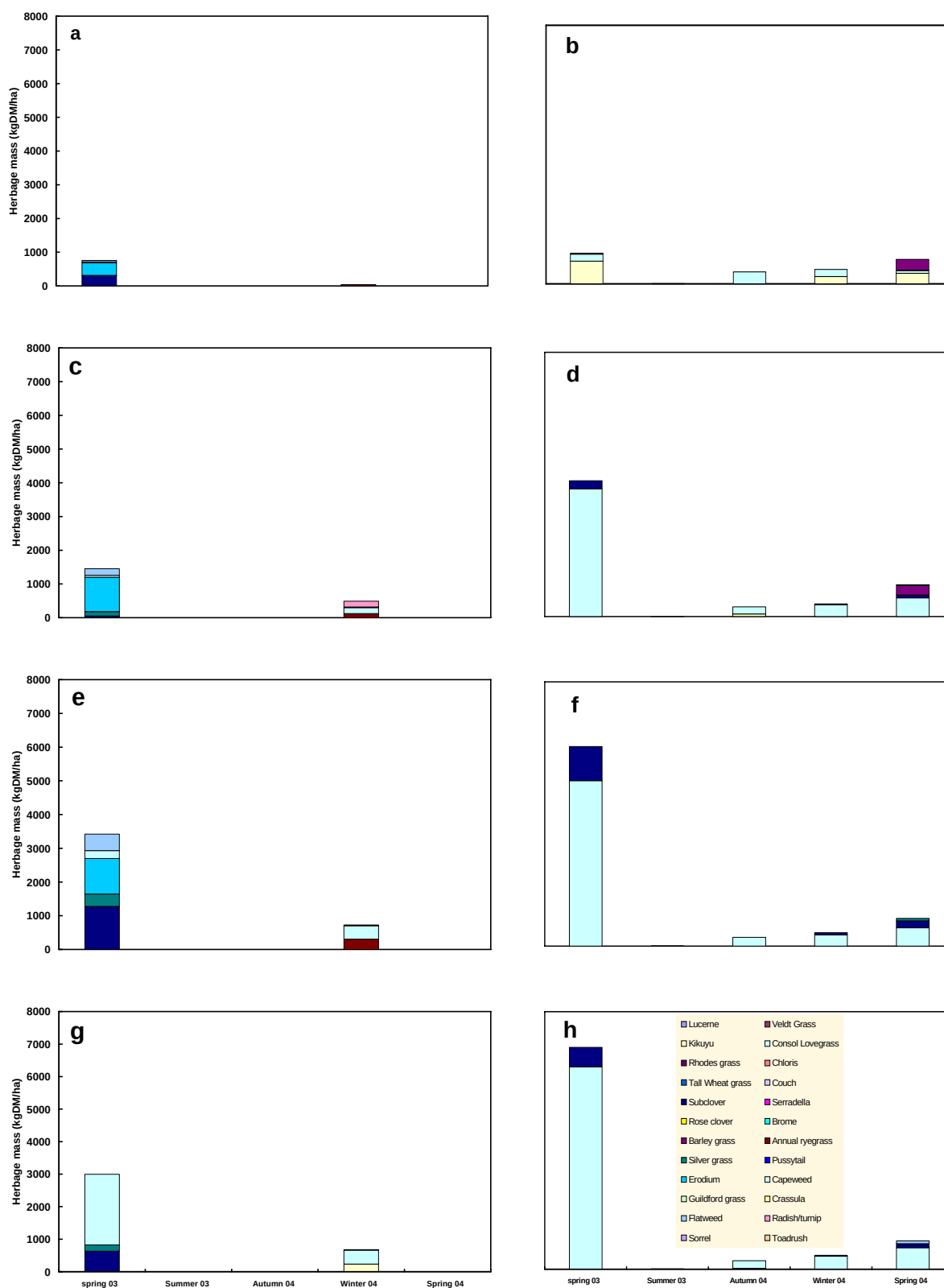


Figure 22. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site G Consol throughout 2003/04. Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show flatweed, capeweed, erodium, silver grass, barley grass, brome, serradella and subclover. Figures b, d, f, h show flatweed, silver grass, barley grass, subclover, consol lovegrass and kikuyu.

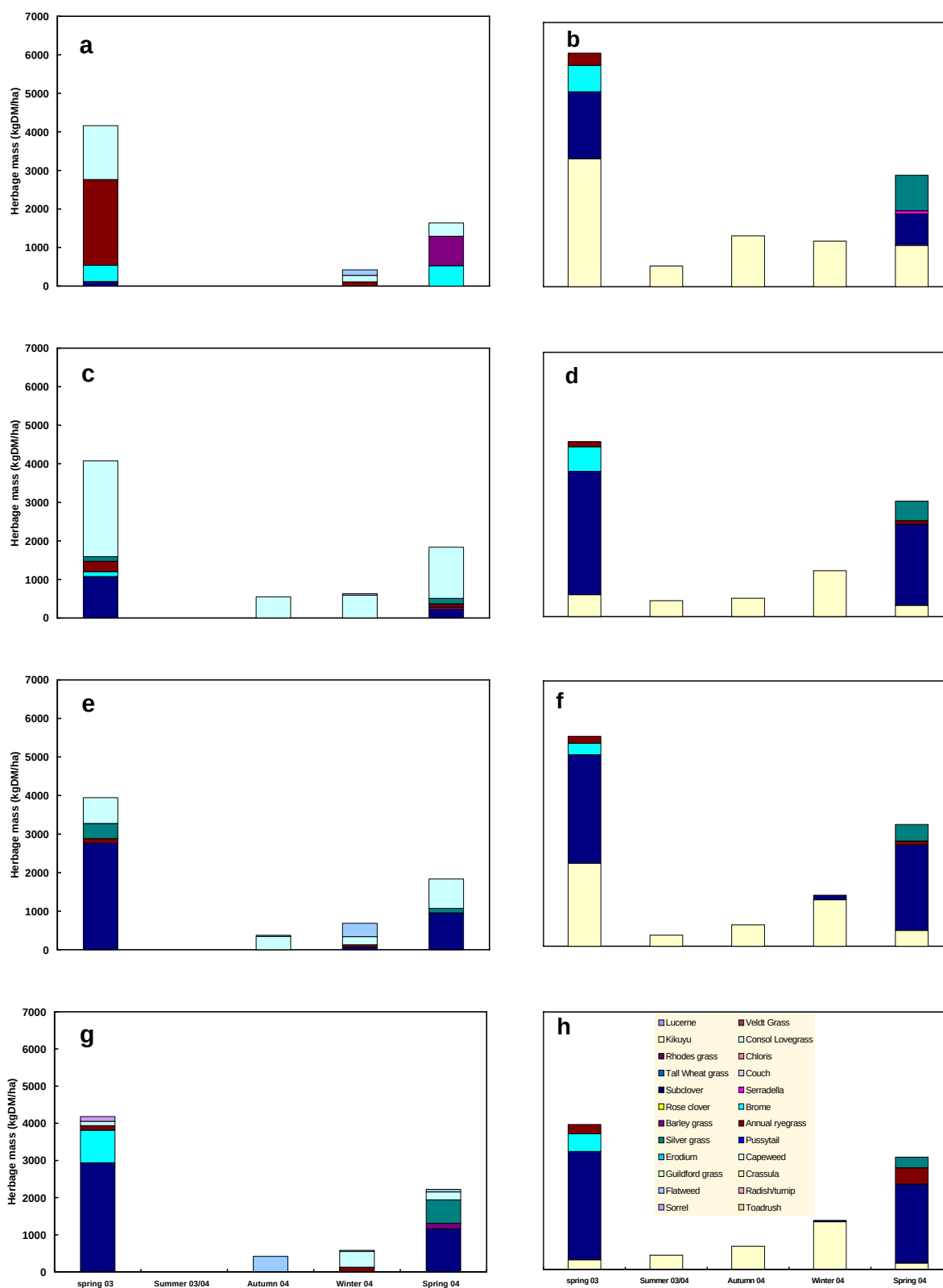


Figure 23. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site H throughout 2003/04. Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g contain flatweed, capeweed, silver grass, annual ryegrass, barley grass, brome and subclover. Figures b, d, f, h show silver grass, annual ryegrass, brome, serradella, subclover and kikuyu.

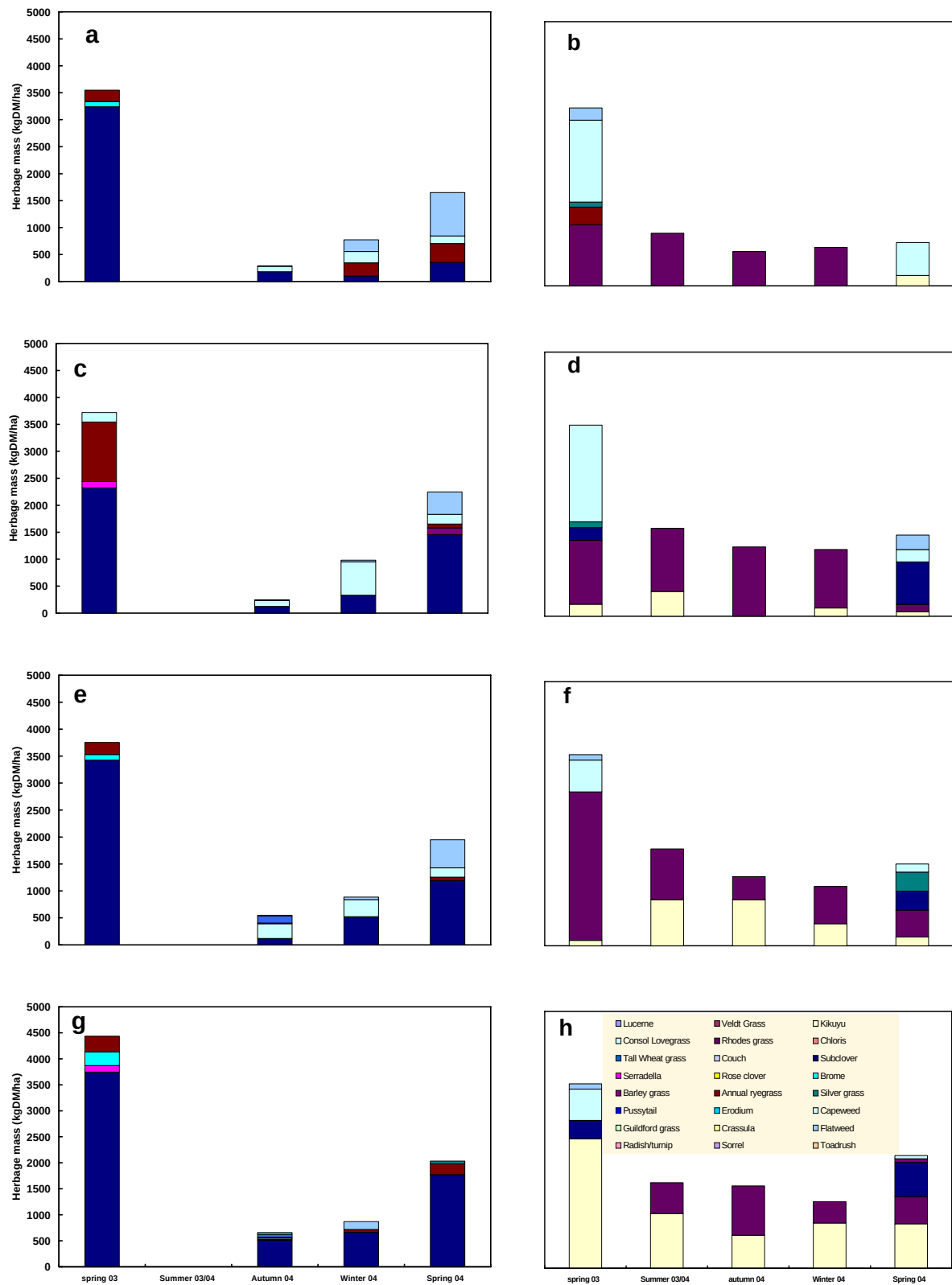


Figure 24. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site I throughout 2003/04. Annual – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show flatweed, capeweed, silver grass, annual ryegrass, barley grass, brome, serradella, subclover and mintweed. Figures b, d, f, h show flatweed, capeweed, silver grass, annual ryegrass, barley grass, subclover, Rhodes grass and kikuyu.

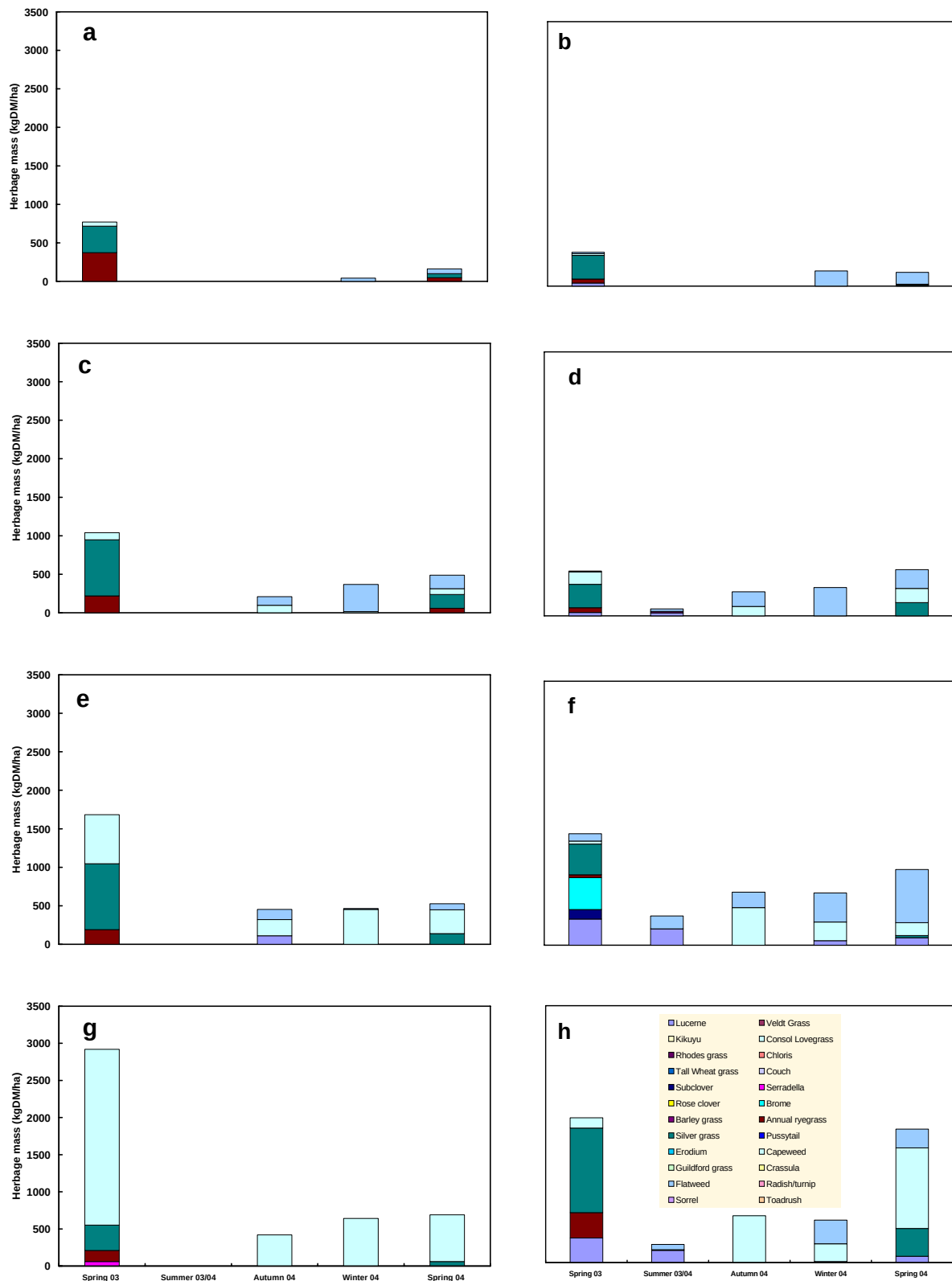
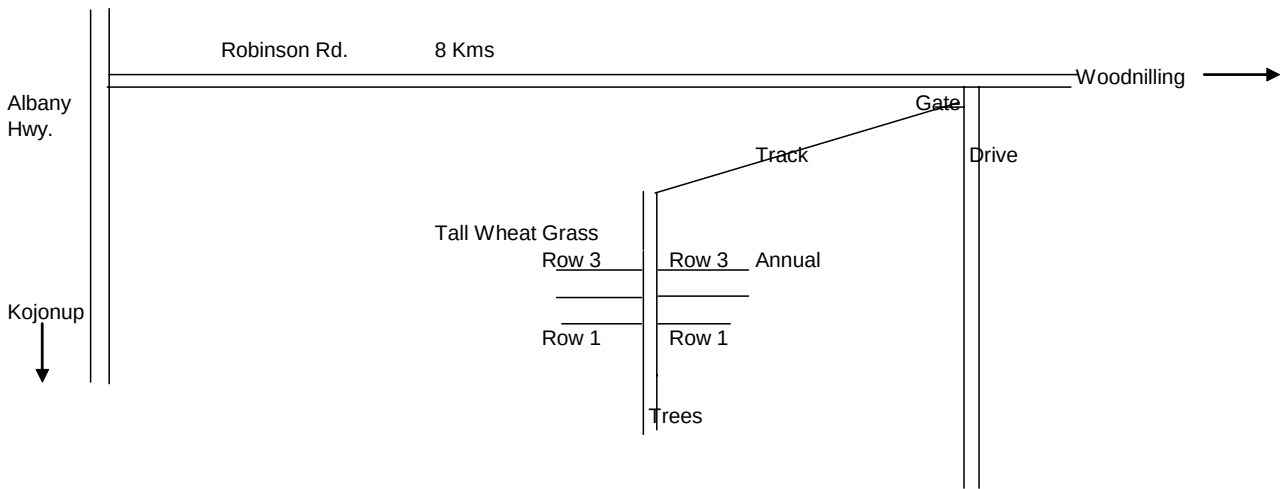


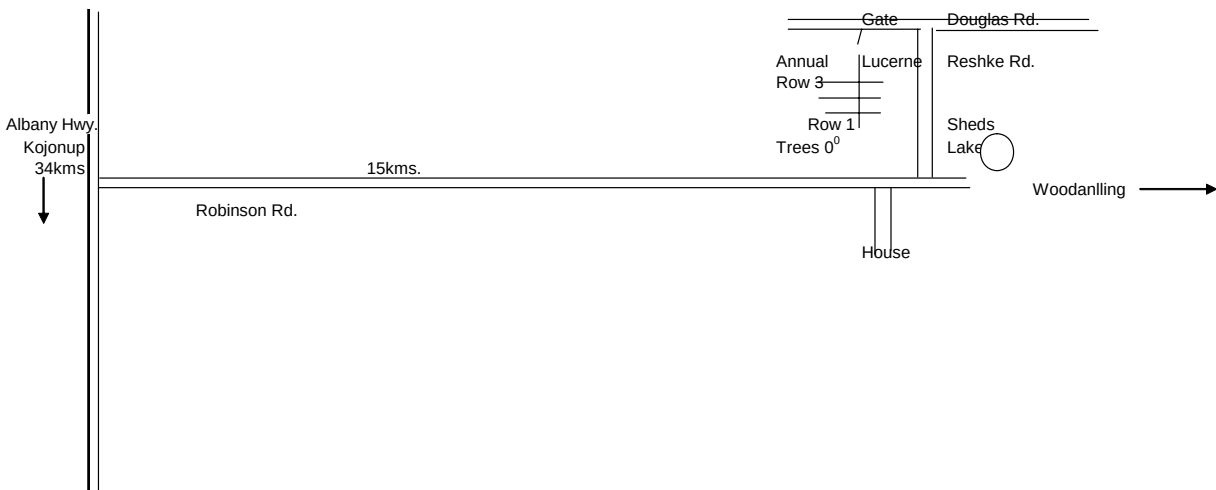
Figure 25. Botanical composition of annual or perennial pasture at various distances (H) from tree lines at Site J throughout 2003/04. Annual Pasture – 0.5 H (a), 1 H (c), 2 H (e) and 4 H (g). Perennial Pasture 0.5 H (b), 1 H (d), 2 H (f) and 4 H (h). Figures a, c, e, g show flatweed, capeweed, silvergrass, annual ryegrass and serradella. Figures b, d, f, h show flatweed, crassula, capeweed, silver grass, annual ryegrass, brome, subclover, Rhodes grass and lucerne.

Site layout

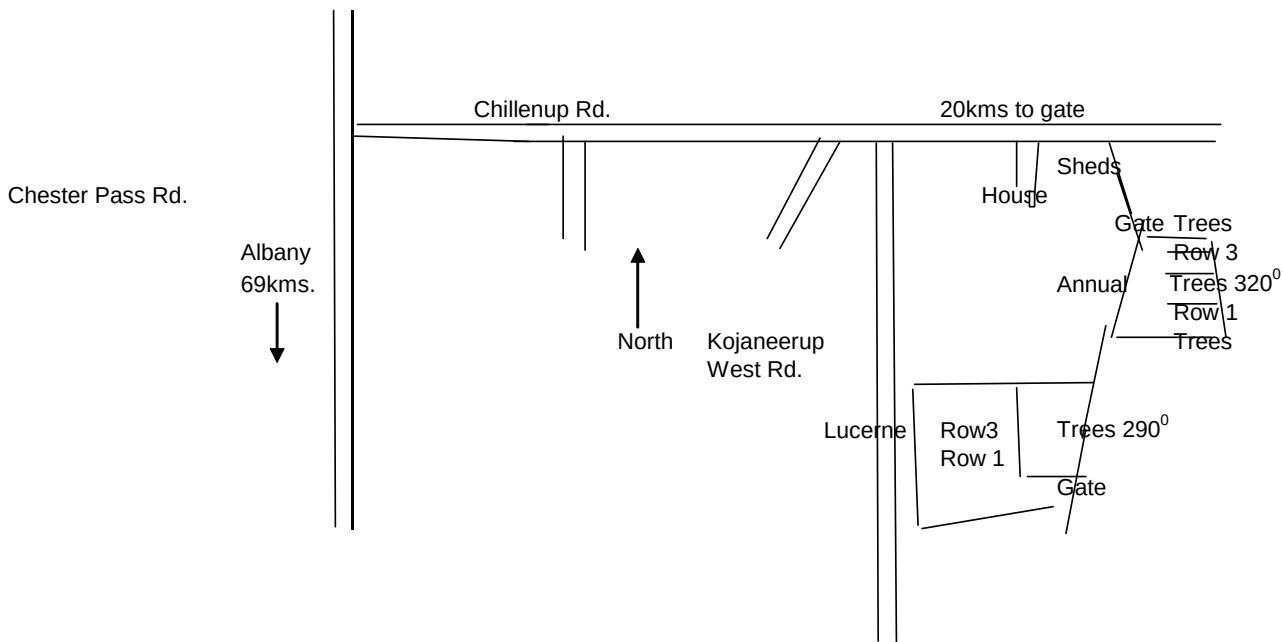
Site A: Thomson



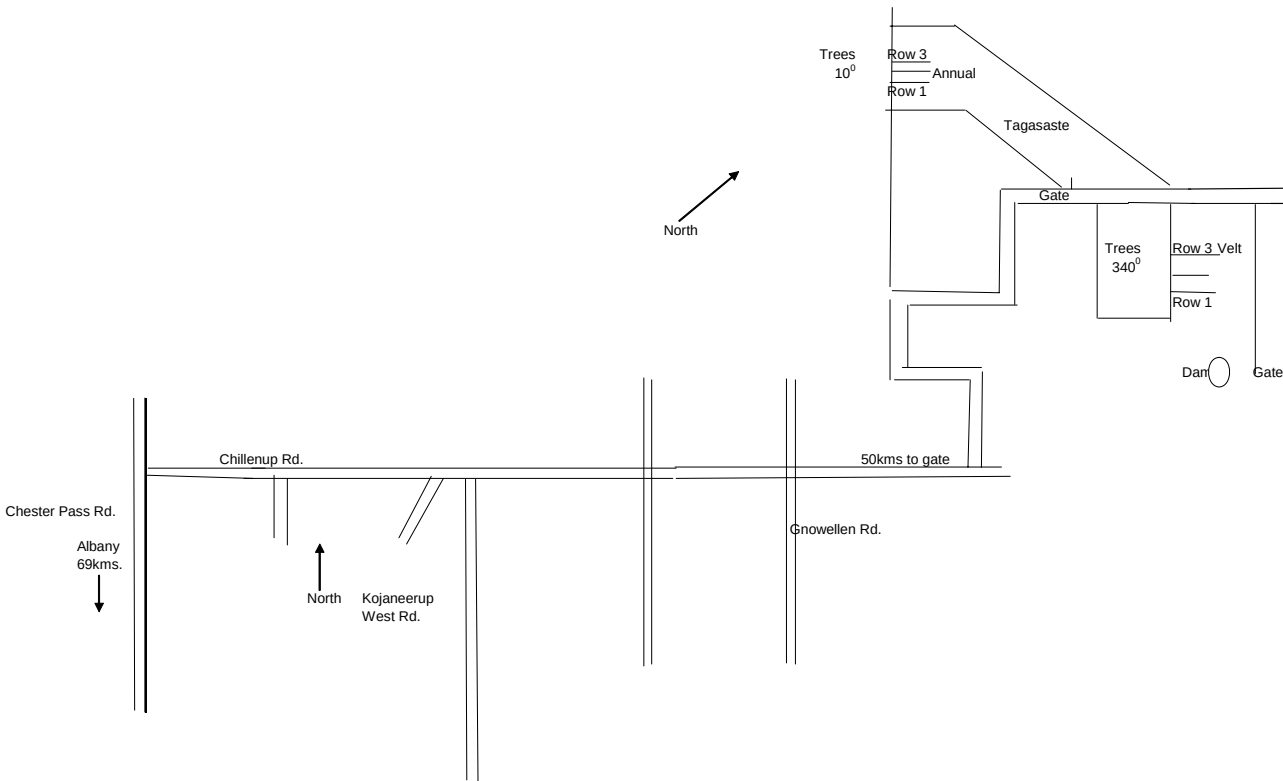
Site B: Pickford



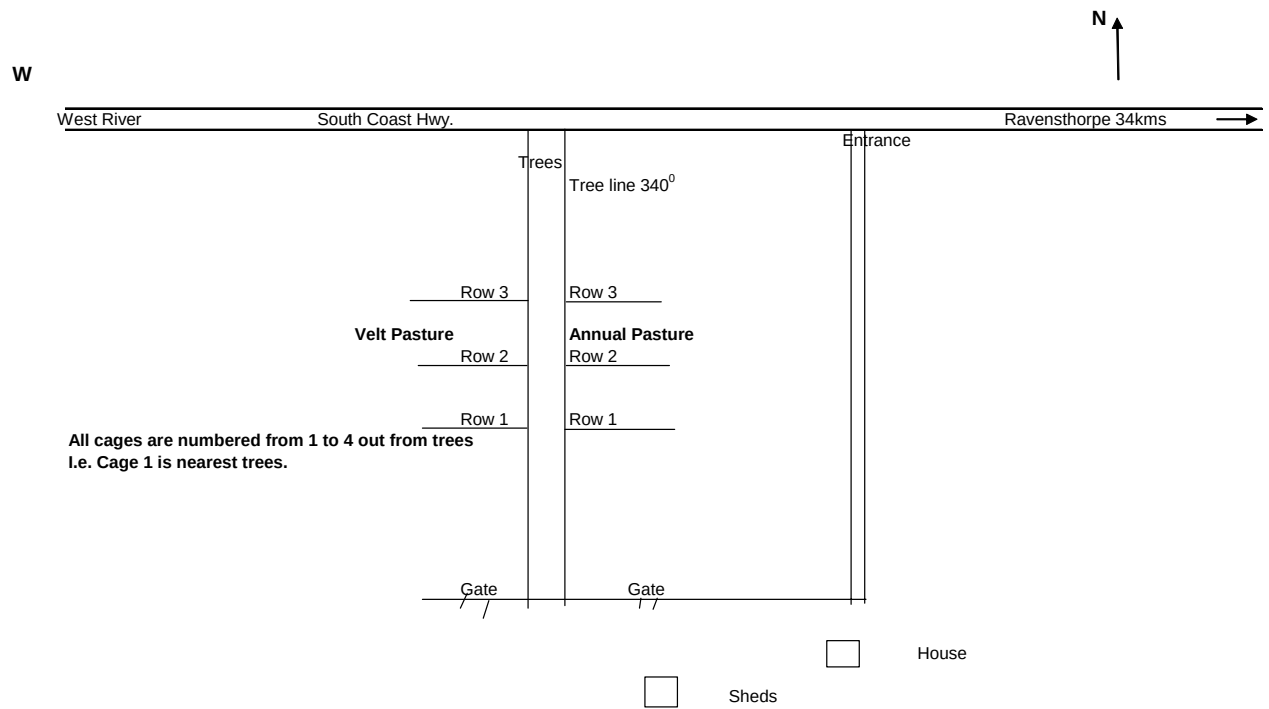
Site C: Shearer



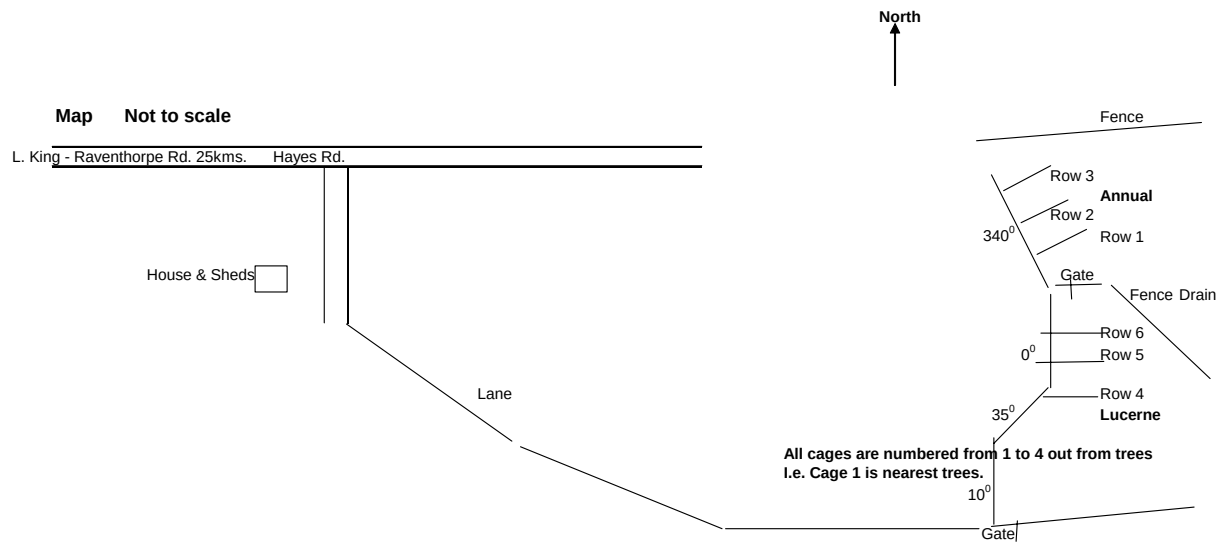
Site D: Subassio



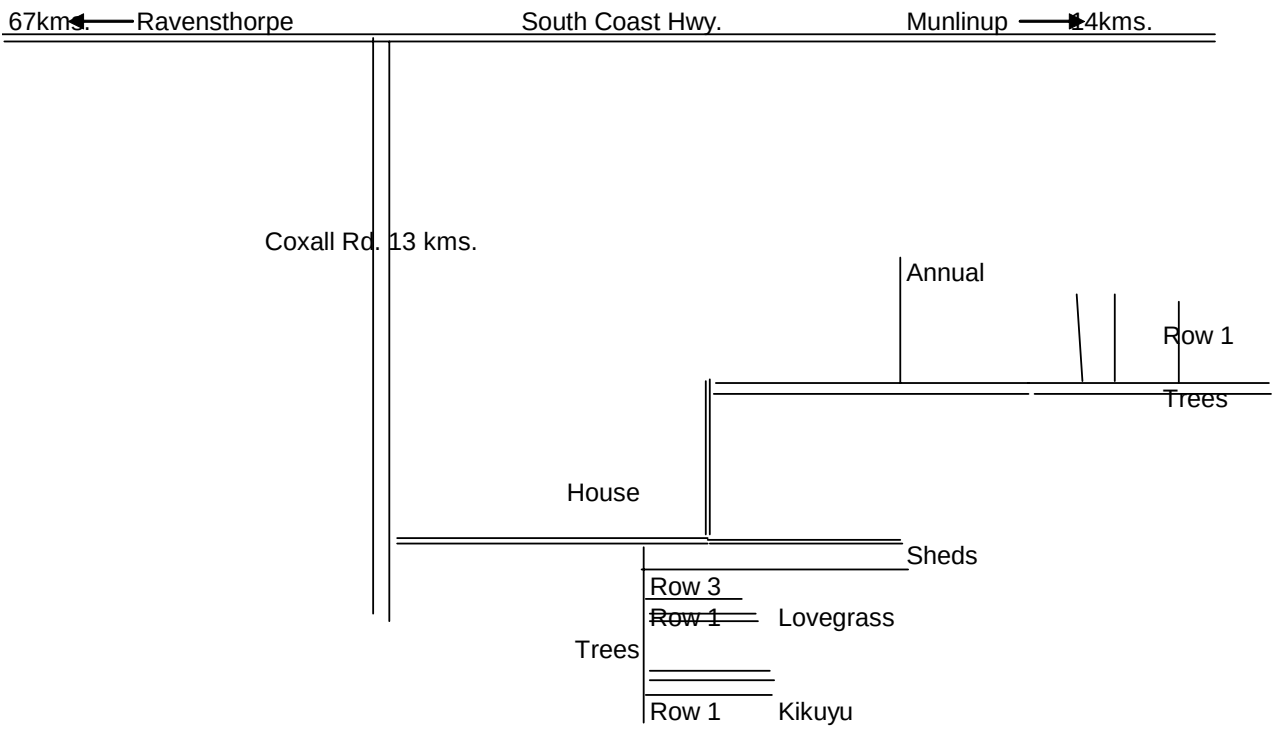
Site E: Caelli



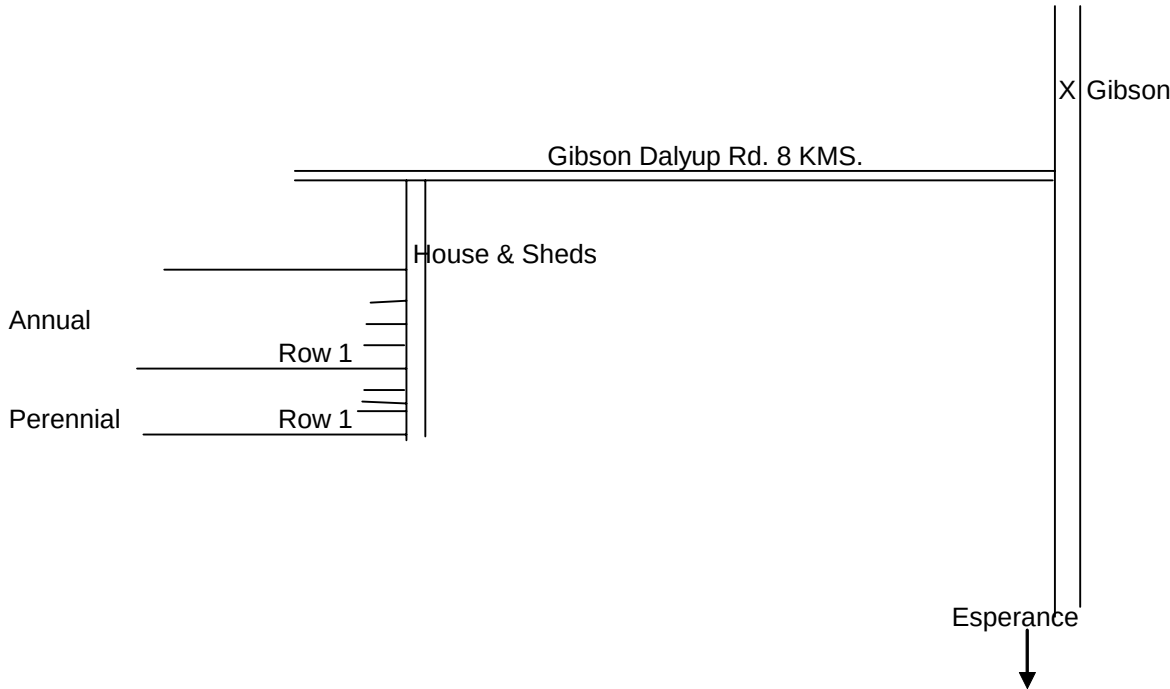
Site F: Tuckett



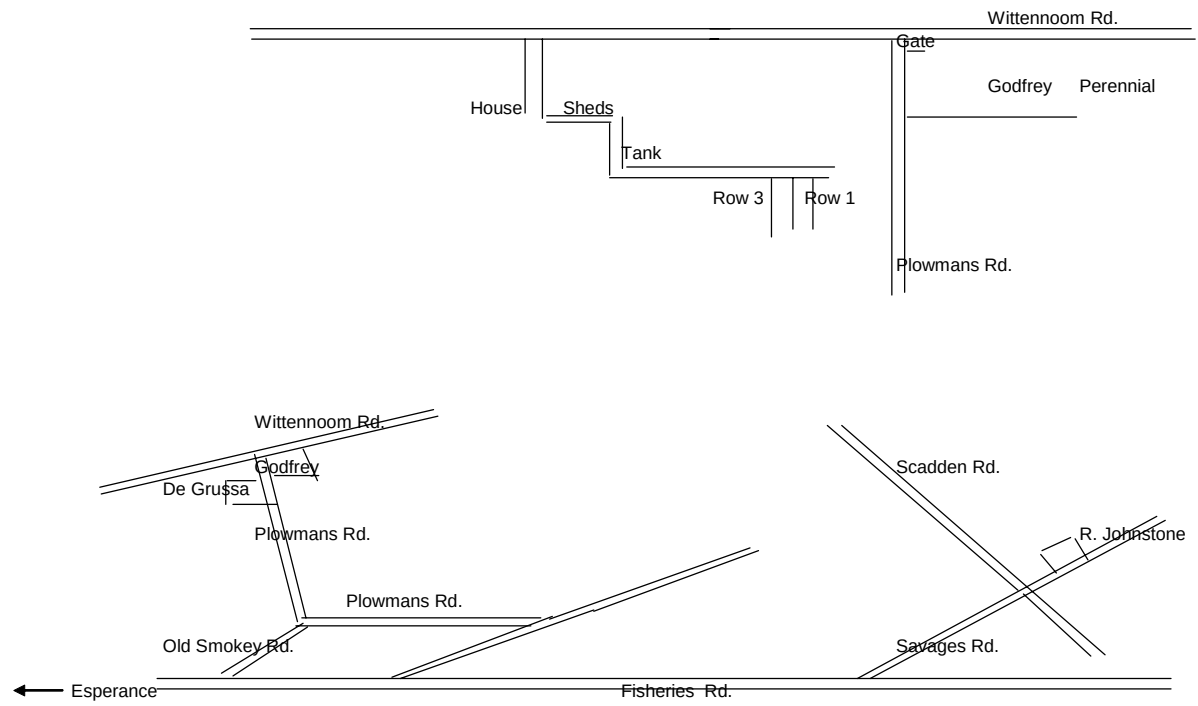
Site G: Silburn



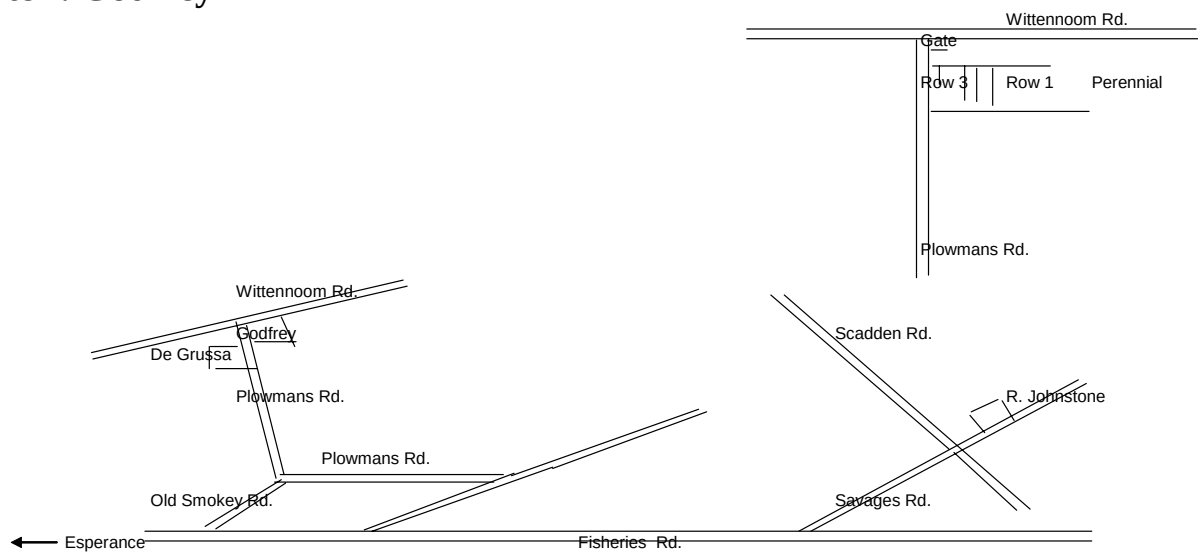
Site H: D. Johnson



Site I: DeGrussa



Site I: Godfrey



Site J: R. Johnstone



8. References

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