Targeted water management planning to maximise water use in a grazing landscape

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Abstract
A conceptual framework of targeted water management planning (TWMP) to maximise landscape water use was developed from a sustainable grazing experiment at Carcoar (average annual rainfall 880 mm) in the central Tablelands New South Wales. The experiment had four pasture treatments – Chicory (CH), sown introduced pastures (SP), fertilised naturalised pastures (FN) and unfertilised naturalised pastures (UN). Two grazing management regimes tactically grazed (TG) and continuously grazed (CG) were imposed. The CH treatment was TG only. Measurements taken from 1999 to 2000 were neutron moisture meter profiles to determine maximum soil water deficit values (SWD_{Max}), soil morphological and hydraulic characterisation, runoff, pasture composition and biomass and selected climatic data. These data were used to develop the TWMP framework.

This data showed that pastures were not capable of preventing deep drainage and lower slope exfiltration at Carcoar. However applying the TWMP framework, pasture systems could be strategically placed in the landscape to maximise wateruse and maintain productivity. in this landscape the TWMP framework would have a strategy of naturalised pastures in the upper slopes, higher water use introduced and native perennials grasses in the midslopes and deep rooted and water tolerant species such as chicory and lucerne in the drainage lines. In all the systems, grazing management is a key element to maintain ground cover and perenniality.

With similar soil and botanical data the TWMP framework could be applied to any landscape.

Keywords
soil water deficit, grazing management, biomass, runoff, Targeted Water Management Plan, water quality.

Introduction

The Central Tablelands of NSW is located in the high rainfall zone (HRZ - >600 mm annual rainfall) and is a major sheep and cattle production area where perennial grass-based pastures provide forage for livestock production. To remain profitable and have higher levels of livestock production, producers have extensively cleared trees and significantly reduced desirable perennial species in both native and sown pastures and increased the proportion of invasive annual grasses (Kemp et al. 1996).

The replacement of native vegetation with shallow-rooted annual species has increased deep drainage below the root-zone (Ridley et al. 1997), a major contributor to increased dryland salinity, soil acidification (Helyar et al. 1990), nitrate leaching (Helyar and Porter 1989) and water quality of local rivers and streams (Gates and Williams 1988). These are major threats to the sustainability of agriculture in the HRZ of New South Wales.

To help address these threats, grazing management based on a strong perennial pasture is being promoted as a viable system, which is also capable of maintaining a profitable livestock enterprise. This system theoretically maximises plant water use and maintains ground cover to reduce runoff and erosion to maintain water quality in water systems. However developing management strategies in the tablelands to achieve better water use is a major challenge due to the high variability in soil type and depth, slope and aspect (King et al. 2004). The same arguments arise with respect to surface runoff.

This paper reports the outcomes from the Carcoar site in the SGS National Experiment . It examines the impact of perennial species on water usage and surface runoff from grazed pastures, and proposes a targeted water management plan to optimise water use for maximum production and beneficial environmental impact on and off-site using a perennial grass pasture system.

Materials and Methods

Site description and experimental design

The experimental site was located near Carcoar, (33°37’ S; 149°13’ E) in the Central Tablelands of NSW (Figure 1). The site is dominated by a westerly sloping ridge with treatment plots having northerly, southerly and westerly aspects (King et al. 2004). Slope ranges from ~1 to 16°, with a median slope of approximately 5° with drainage patterns that generally converge into concave drainage basins. Soils were light textured brown chromosols and kurosols (Isbell 1996) with low fertility. Annual average rainfall for Carcoar is 871 mm. From 1997 to 2002, meteorological data and soil temperature were collected from an automatic recording station located in the centre of the site every 15 minutes. ‘Data Drill” SILO data set was used to fill missing or long term data.

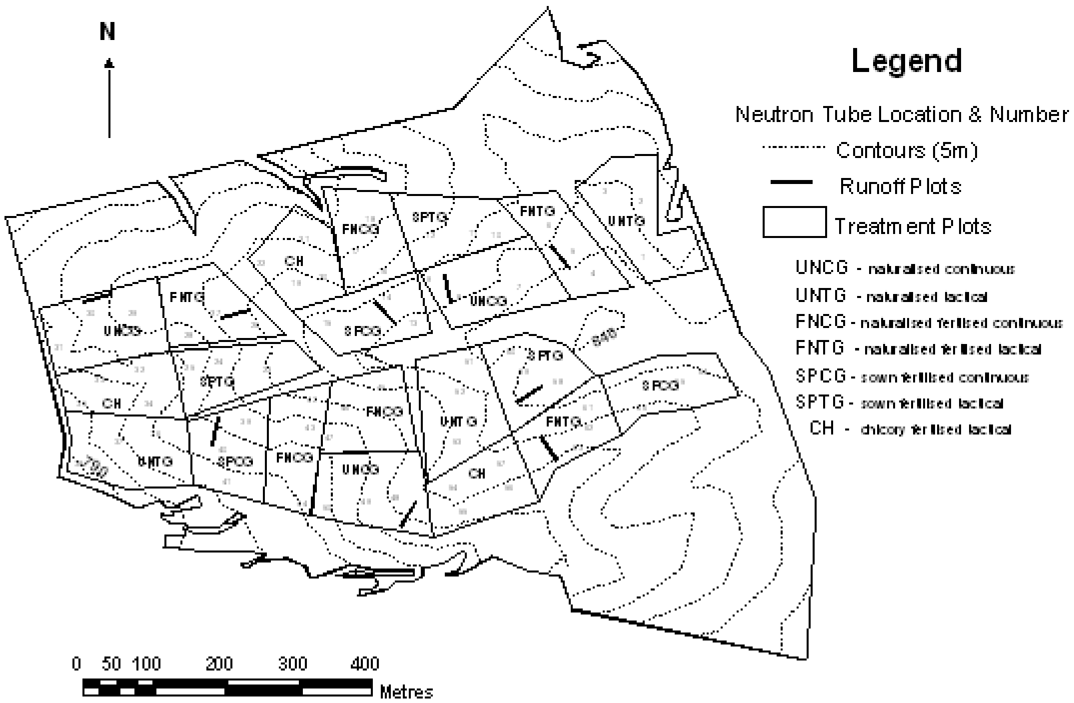


Figure 1. SGS Carcoar site - location of runoff plots, NMM access tubes, plot boundaries and site elevation.

The existing vegetation can be described as ‘degraded naturalised pasture’, composed of 20 % native perennial grasses with annual grasses, annual legumes and broadleaves (King et al. 2004). Treatment imposed to obtain four pasture systems –naturalised - UN, naturalised + fertiliser - FN, sown perennial grass + fertiliser – SP (lime and sod-seeded perennials and annual clovers) and chicory + fertiliser - CH). The sown treatments were established in autumn 1998. Two levels of grazing management, continuous - CG and tactical - TG were imposed in an incomplete 4 x 2 factorial and replicated 3 times. There was no continuously grazed chicory.

Soil water measurements

A network of 66 aluminium tubes (Figure 1) was installed to measure soil water content (SWC) using a neutron moisture meter (NMM). Tubes were installed to a depth of 2 m to allow readings at 20 cm intervals to 1.8 m. Three tubes were installed per treatment in the upper, mid and lower slope. Care was taken to visually avoid obvious wet and dry areas and rocky outcrops. The chicory plots had a single tube in each of the 4 sub plots. Soil horizon depth (A1, A2, B and C horizons), colour and texture were described to a depth of 1.8m adjacent to the access tubes.

Runoff quantity and quality
Nine runoff plots (Figure 1) measured quantity and quality of runoff for a range of slopes (low, medium and steep) and pasture type/management (UNCG, FNTG and SPTG). Runoff was collected from enclosed 100 m^2 plots. Manual or tipping bucket rain gauges were installed adjacent to each runoff plot. Gypsum blocks were installed near the runoff flumes in the A1, A2 and top of the B horizons to measure soil moisture status. A slotted tube was located on the tipping bucket to collect a small continuous water sample during runoff events between October 2001 and May 2002. Samples were analysed for total suspended solids (TSS), total phosphorus (P), total nitrogen (N) and total organic carbon (TOC).

Soil physical measurements
On each treatment plot, measurements of near saturated conductivity (Ks = -20 mm suction) were carried out on the surface, the A2 and on the top of the B horizon using a disc permeameter (Perroux and White, 1988). Soil bulk density was determined for each layer. Saturated hydraulic conductivity of the C horizon was measured at three locations using a well permeameter. Soil samples were taken from the soil surface and B horizon to determine water holding capacity (WHC).

Field capacity and the calculation of soil water deficits (SWD)
The field capacity (FC) was determined to be the water content (mm) of the soil profile when fully wet (White et al. 2003). This was determined to be the wettest NMM recorded for each individual access tube. SWD was calculated as the difference between the tube profile FC and the tube profile water content when measured to estimate and compare potential recharge. we were confident of the methodology as the soil moisture content at the estimated FC was close to the field capacity determined by laboratory soil moisture characterisation.

Plant measurements
Green herbage mass (kg DM/ha) and perennial composition (i.e. C3 and C4 species) was estimated at 50 quadrats (60 quadrats in CH) in each treatment plot at 6 weekly intervals using procedures described by Dowling et al. (2004). Measurements were also taken in the runoff plots.

Landscape characterisation
To help characterise and explain the landscape the following procedures were used
- Fuzzy Landscape Analysis Geographic Information System (FLAG) (Roberts et al. 1997).
- Flow accumulation - modelled using digital elevation model (DEM) data and the ArcINFO routine of Jenson and Dominigue (1988).
- Irradiance - modelled across the landscape using the ArcINFO routine of Kumar et al. (1997).
- Electro magnetic induction (EMI) - A survey was conducted in February 1998 with an EM31.

Biometrical analysis
Analysis mainly used a one way analysis of variance (ANOVA) model except in the comparison of maximum soil water deficit (SWD_{Max}) when treatment effects sums of squares was orthogonally partitioned into 3 treatment groups based on perenniality: (i) low perenniality (UNCG, FNCG, FNTG), (ii) medium perenniality (UNTG), and (iii) high perenniality (SPCG, SPTG, CH).

Results
Variability between access tube locations.
Due to the large number of environmental factors that may have influenced the NMM variability, a number of the factors outlined in the methods and considered important were compared using the treatment mean values (Table 1). These show that there is no valid or consistent reason to eliminate any of the access tubes from the SWD analysis despite the inherent variability. Also the visual location of the tubes across the site were generally consistent in that they avoided the extreme wet and dry positions. From this table perenniality is the only measured variable that differs between treatments at NMM location.

Table 1. Mean values for environmental factors at the NMM tube location within each treatment.

Factor	Treatment							P value
	CH	SPTG	SPCG	FNTG	FNCG	UNTG	UNCG	
FLAG wetness index	0.245	0.187	0.251	0.201	0.316	0.206	0.140	0.484
Flow accumulation (m^2)	32.6	7.8	15.4	17.3	14.9	12.3	21.0	0.533
Slope (%)	6.59	5.30	6.27	6.34	7.44	6.16	5.62	0.135
Irradiance @ 22 June (MJ m^{-2}.day)	8727	8988	9008	8345	8070	8809	9484	0.608
Ks surface (mm hr^{-1})	6.98	12.46	8.90	6.52	12.09	6.71	5.87	0.196
Ks B horizon (mm hr^{-1})	1.76	2.60	1.78	1.02	2.87	1.48	2.01	0.239
A horizon depth (cm)	28.9	25.7	24.3	25.6	22.5	25.9	27.1	0.141
EM-31 reading (ECa)	31.7	32.8	32.3	32.5	29.3	32.0	31.9	0.897
Perenniality (% herbage mass in May 2001)	67	84	67	54	35	70	48	0.006

Effect of pasture type and grazing system on SWD

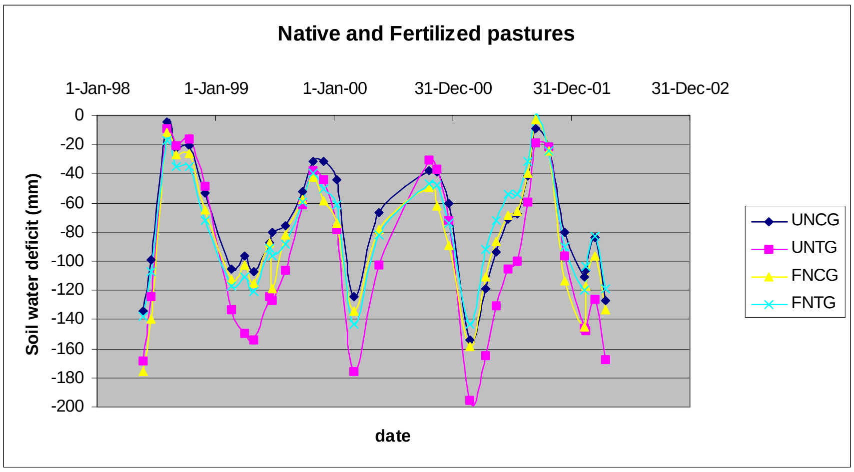
Mean SWD measured for the pasture types and grazing systems over the measurement period (1998 to 2002) are shown Fig. 2 (a) & 2 (b). Soils were near or at field capacity over the August to October period and dried out over summer with SWD_{Max} measured in the February to April period each year. The highest SWD_{Max} of -195 mm was measured in February 2001. For naturalised and fertilised pasture, the UNTG treatment had a greater SWD_{Max} ($P<0.05$) than UNCG, FNCG and FNTG (Figure 2(b)). In fact, UNTG mirrored the results for sown pastures (SPCG, SPTG and CH treatments) with similar SWD_{Max} in 2000 and 2001 (Figure 2 (a)).

In 1999 the mean SWD_{Max} for pasture types showed that the SPCG treatment with a mean of 176 mm significantly dried out the soil over the summer-autumn more than the native and fertilised pastures - UNCG, FNCG and FNTG . In 2000, UNCG, FNCG and FNTG were again the wettest profiles compared to UNTG with a SWD_{Max} of -176 mm which was not significantly different from the SP and CH treatments. A similar pattern was observed in 2001 and 2002, with the driest profile measured in the UNTG treatment and the three other natural pasture treatments (UNCG, FNCG and FNTG) having the lowest SWD_{Max} (Figure 2 (b)). The numerical values of these groupings and their significance are shown in Table 2.

Relationship between SWD_{Max} and perenniality.

To examine the relationship between perenniality and soil water usage, treatments were grouped based on the perennial component measured in May 2001 (Table 2). These included Group 1 – UNCG, FNCG and FNTG , Group2 – UNTG , and Group 3 – SPCG, SPTG and CH. The perenniality in Groups 1, 2 and 3 were 46%, 70 % and 73 % respectively. These showed that sown perennial grasses and chicory consistently dried out the soil over the late spring through mid-autumn period, regardless of grazing treatment. In 1999 and 2000, all naturalised pastures expect UNTG were less efficient at drying out the soil over summer, but showed a progressive improvement of in the $SWD_{Max.}$ Important to note is that by 2000 the UNTG treatment however dried the soil similarly to the sown pastures and was significantly ($P<0.05$) drier than the other naturalised pasture treatments.. This was due to the C4 perennial grasses increasing in the UNTG and progressively diminishing the fertilised and sown treatments. For each pasture type, tactical grazing management increased C4 herbage mass and particularly where no fertiliser was applied (UNTG).

(a)



(b)

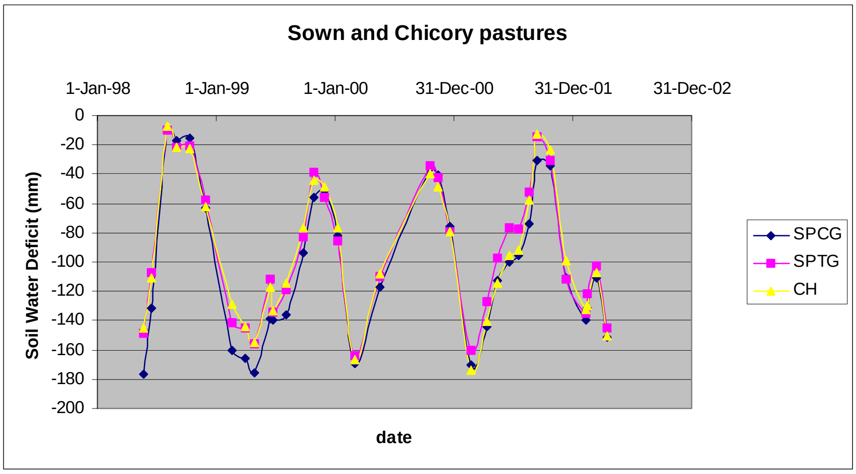


Figure 2 (a) & (b) - Mean SWD over time (1998 – 2001) measured to 1.8 m depth in the seven treatments.

Table 2. Comparison of soil-water deficit means across three perenniality treatment groups for 1999-2001. Group composition is: Group 1 (UNCG, FNCG & FNTG), Group 2 (UNTG) and Group 3 (SPCG, SPTG & CH).

Year	**Perenniality**			**LSD(5%)**		**Significance level**		
	Gp1	**Gp2**	**Gp3**	**Gp1 & 3**	**Gp2**	**Gp1**	**Gp1**	**Gp2**
	Low	Medium	High	v's	v's	v's	v's	v's
	(n=9)[A]	(n=3)	(n=9)	Gp2	Gp3	Gp2	Gp3	Gp3
1999	-119	-157	-162	25	17	<0.01	<0.001	ns[B]
2000	-134	-176	-167	26	18	<0.01	<0.01	ns
2001	-152	-195	-169	31	22	<0.01	ns	ns

[A] Number of observations per mean; [B] not significant (*P*>0.05)

Groundcover and herbage mass effects on runoff and water quality.
Groundcover was not a variable in the determination of runoff and water quality because 95% of the runoff events had a ground cover percentage >94%. Runoff was likely only when rainfall events exceeded 20 mm; and when herbage mass was >2000 kg/ha. On average for the experimental period, runoff accounted for only 3% of rainfall received while the median runoff for all rainfall events >5 mm was 0.2%.

Analysis of runoff samples for N and P collected from the UNCG, FNTG and SPTG compared with long and short term trigger values for irrigation water quality (Table 2) (Anon, 2000). The median values for N and P were below the STV (Table 32). The median N value was just above the LTV whereas the value for

P was six times greater than the LTV. The maximum values were at the low end of the STV values for both elements.

Table 3. Median and maximum values of total nitrogen (N) & phosphorus (P) (mg L^{-1}) measured in runoff samples collected at Carcoar and compared with long- (LTV) and short-term (STV) trigger values for irrigation water quality.

	Mean ± sd (mg L^{-1})	Maximum Value (mg L^{-1})	LTV in irrigation water [A] (mg L^{-1})	STV in irrigation water[B] (mg L^{-1})
Total N	5.47 ± 3.88	27	5	25 - 125
Total P	0.71 ± 0.56	3.1	0.05	0.8 - 12

[A] Long term trigger values up to 100 years; [B] Short term trigger values up to 20 years.

These values were in excess of the south-east Australia aquatic ecosystem trigger values for total N and total P (Anon, 2000). The relationship between runoff and total P total N and total suspended solids removed in the runoff (kg ha^{-1}) were determined but cannot be discussed in this paper. There were significant regressions, which are discussed more fully in Packer et al 2004.

Discussion

Planting trees and restoring native vegetation has become an immediate response to recharge management for salinity control. However reafforestation of entire recharge zones is impractical and uneconomic. As an alternative the maintenance of long term perennial pastures is proposed as a feasible alternative for water management in the HRZ (Singh et al. 2003). Perennial-dominated pastures efficiently utilise soil water and prevent soil erosion and nutrient loss. Unfortunately, due to pressure for higher stock returns perennial grass composition has significantly declined and there needs to be a significant increase to reduce recharge. Tactical grazing management at Carcoar showed this was possible with an increase in the proportion and availability of perennial grasses (both native and sown) compared with continuous grazing (Dowling et al. 2004). However perenniality was not sufficient to prevent deep drainage in the HRZ but grazing management was able to have a larger soil moisture 'bucket'. Grazing management increased perennial grass content from 20 to 65% would increase SWD_{Max} by 30 mm

Also important is the maintenance of biomass or herbage mass particularly green herbage mass which in conjunction with SWD_{Max} determine transpiration rate. The Carcoar data suggest that most of the impact on SWD_{Max} is gained when perennial herbage mass is maintained at ~2000 kg/ha, a minimum biomass benchmark similar to that required to reduce runoff and to ensure livestock performance meets market targets (Bell 2000). Determining a benchmark is important as producers are becoming more competent at making management decisions based on herbage mass.

One aspect that was noted was the differential effect of perennial grass species on SWD_{Max} at similar levels of perennial herbage mass. Overall, sown perennials created a larger SWD than natural pasture, irrespective of grazing management and fertiliser strategy, except for the UNTG treatment. The difference in SWD increased to a maximum of 15 to 30 mm at a perennial herbage mass of 3000 kg/ha, depending on grazing treatment. Continuously grazed sown pasture (SPCG) dried out soil more than tactical grazing because the more intense grazing treatment maintained more green leaf over summer. In contrast to the other natural pasture treatments, tactical grazing (UNTG) significantly increased SWD_{Max} to >-200 mm, when perennial grass herbage exceeded 2500 kg/ha. However there was a botanical composition change rather than perennial herbage mass change due to an increase in the proportion of C4 species, particularly kangaroo grass (*Themeda australis*). These results suggest that deep drainage is reduced in the order native C3 grasses < sown C3 grasses < mixed C3/C4 grasses when present at the same level of herbage mass. This highlighted the potential to use grazing management and species to modify herbage mass and type for maximising SWD.

Maintaining a high perennial content of desirable species composition was also important to control the amount and quality of runoff. At Carcoar the proportion of runoff relative to rainfall rarely exceeded 8% and is more likely to be 3% or less except when a rainfall event is high (>50 mm) and herbage mass is low (<2000 kg/ha). However it was observed that the major runoff source in this landscape was in the drainage lines and lower slope areas and is suggested would be higher than the measured 3% average. Therefore these areas should have high water use species in this area for maximum water use and to control runoff water quality. Sub surface flow was observed as another major pathway of water movement in the landscape. The use of active perennial grasses is suggested as a viable option to intercept this flow in the mid slopes.

Therefore a concept that was developed from this work would include a herbage mass 1- 2 t/ha, groundcover above 70% with a reasonable perennial base (70%) using active but controlled grazing. With this base a Targeted Water Management Plan (TWMP) was designed at a farm scale to achieve optimal landscape water use. This plan included:

- A naturalised pasture species in the drier upper slopes where the soils are shallow, less fertile and acidic. They would be ideally dominated by high quality native perennial grasses (eg. *Microlaena* and *Austrodanthonia* spp.) suitable for biodiversity or livestock production.
- Locating introduced grasses in the midslope areas that receive a more reliable supply of water from a combination of rainfall, exfiltration and surface runoff. These midslopes generally have more fertile and deeper soils that are also more suited to support long term sown pastures or native pastures such as *Microlaena* spp.
- Establishing deep rooted and water tolerant species such as chicory and lucerne in the drainage lines to enable maximum water use in the wettest areas. This would help dry the profile to depth and extend the growing season to provide summer forage for increased productivity such as finishing prime lambs to market specification (Holst et al. 2004).

Data from Carcoar also suggests a TWMP should consider fertiliser application timing to maintain perenniality and total green herbage mass for maximum water use. Discussion on this is expanded in Packer et al 2004.

Conclusion

While salinity problems are manifest at broad landscape scales, the primary cause is farming practice at the farm or paddock scale (Keating et al. 2002). This does not mean that productivity has to be compromised. The Carcoar site has shown that grazing management can significantly affect both perennial amount and type. This has implications to water use to help prevent drainage past the root zone and high quality runoff for improved water quality. The unique aspect of this data is that it was possible to target the diverse range of species both native and introduced combined with a grazing strategy to gain maximum water use in a highly variable landscape. This would be based around minimum standards of herbage mass of 1- 2 t/ha, groundcover above 70% and a reasonable perennial base about 70%. This approach would be much more palatable to landholders that wish to achieve an environmental outcome and maintain productivity as opposed to environmental solutions of complete reafforestation.

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