Forage species in acid sulfate soil backswamps: a comparison of 'wet' and 'dry' management strategies.

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Abstract

The soil chemistry and pasture productivity was assessed in two adjacent acid sulfate soil backswamps. While the sites had similar elevations, soils and groundwater chemistry they also had a long term difference (> 30 yrs) in their respective water management strategies. One site (Morans) was 'wet managed' with annual harvesting of freshwater from the adjacent river system by opening floodgates and using penstocks to retain surface water. The other site (Sweenys) was 'dry managed' and was drained in a passive fashion with no attempt to impede drainage or retain any surface water. The largest differences in biomass were evident in the *Paspalum distichum* ecotone, with Morans having higher biomass than Sweenys. Much of Sweenys backswamp was scalded and bare due to high concentrations of solutes and acidic ions in near surface soils. The solutes and acidic ions were derived from upward evaporative flux of sulfuric horizon groundwater from the capillary fringe. The 'dry managed' site was lacking a surface organic layer – an important feature which effectively enhanced the process of upward evaporative solute accumulation. While 'wetter' management can encourage surface organic matter accumulation, thus reducing upward evaporative flux of toxic solutes and thereby improve biomass / productivity over time, this is not a certain outcome as gains made in surface organic matter accumulation can be easily destroyed by other management activities such as overstocking or fire. Further research at a wider range of ASS backswamp sites is required to determine optimum requirements for whole grazing system management that maximise both productivity and water quality outcomes.

Introduction

Large changes have occurred to the hydrology and vegetation in acid sulfate soil (ASS) backswamp wetlands following European occupation and drainage (Smith 2002). Increased drainage has generally led to dryer systems with shorter hydroperiods, encouraged the acidification of surface soils and a subsequent expansion in the area of dry adapted pasture species. Over-drainage of ASS backswamp can lead to off-site impacts on estuarine water quality (Sammut *et al.* 1996) and the acidification of surface soils can produce severe scalding, causing subsequent reductions in pasture productivity.

In ASS backswamp grazing areas there are two main types of hydrology management employed by graziers. The first type ('dry-managed') is essentially passive, with surface water drained as quickly as possible using the existing drainage infrastructure and encouragement of dryer adapted pasture species in the backswamps area. Such systems are often run with relatively uniform stocking rates and no attempts are made to impede drainage. The second type ('wet-managed') involves more active management of the hydrology and usually some kind of impediment to the existing drainage system and / or strategic harvesting of fresh water from the adjacent river system. This style of management produces a hydrology that, while still much dryer, is more akin to the original backswamp conditions. Such systems are often run with seasonal stocking rates in conjunction with higher elevation country. There are anecdotal reports that this second style of management can result in better pasture productivity, less acidification of surface soils and reduced export of acidity.

This study aims to (1) compare and assess soil and water acidification processes in a 'wet-managed' backswamp and a 'dry-managed' backswamp which have similar soils, and groundwater chemistry and (2) compare their pasture biomass / seasonal growth in their respective *Paspalum distichum* and *Cynodon dactylon* ecotones.

Materials and Methods

Site selection, surveying and meteorological data

The comparative studies were conducted in two sites (Morans and Sweenys) located in ASS backswamps on the lower Clarence River floodplain (Fig. 1). The two sites had elevations close to mean sea level and a long term difference in the water management strategies employed by the respective graziers. Morans swamp had been actively 'wet managed' for over 30 yrs with annual harvesting and retention of freshwater from the river within the swamp by opening floodgates and using penstocks to retain surface water. Sweenys swamp was essentially 'dry managed' since initial drainage and no harvesting or intentional retention of surface water occurs at this site. A transect (~250 m) was established at each site in the *Paspalum distichum* and *Cynodon dactylon* ecotones, perpendicular to the slope (elevation range of transects ~0.3 to 0.5 m). Each transect was surveyed using an automatic level and staff.

Rainfall, solar radiation, temperature, humidity, wind speed and soil temperature was recorded hourly with an EIT® E-Tech weather station located near the backswamp at Morans (Fig. 1).

Pasture sampling

Two to four pasture cages (1.5 m x 1.0 m) were established in both vegetation types at each transect to exclude cattle from grazing. Pasture cuts were taken from a 0.2 m x 0.2 m area in each cage on a monthly or bi-monthly basis from August 2001 to September

2002. An estimate of groundcover (%) was made in each ecotone on each occasion. Samples were oven dried at 45°C for 96 hours, weighed and then separated into dead and green vegetative material before being re-weighed. Dry matter yields reported for each sites ecotone are the mean of all the pasture cages situated in that ecotone.

Soil surveying and analysis

At each transect a soil core was collected from each ecotone using a jarret and gouge auger to a depth of ~1.6 m. Profiles were described according to McDonald *et al.* (1990). Soil samples were collected at 0.02 m, 0.2 m and every 0.2 m thereafter to a depth of ~1.4 to 1.6 m below ground surface. Samples were carefully handled to avoid oxidation of sulfides. Soil samples were oven dried at 85° C within 48 hrs of collection and crushed to pass a 2 mm sieve. The pH and EC of a 1:5 water extract was determined for each sample (Rayment and Higginson 1992) and select samples analysed for reduced inorganic sulfur species (S_{Cr} - Sullivan *et al.* 2000) and total actual acidity (TAA - Ahern *et al.* 1998; Lin *et al.* 2000), water soluble Cl^- and SO_4^{2-} (Ion chromatography - APHA 4110). Samples of surface soils (0-2 cm) were also collected periodically from within the *Paspalum distichum* ecotones at each site in the vicinity of the pasture cages using a push corer and were analysed according to the methods outlined above.

Groundwater surveying and sampling

Piezometer wells were installed at both study sites in each ecotone. Each piezometer consisted of a 10 cm diameter hand augured hole about 1.4 m deep, with a 5.5 cm diameter slotted and screened PVC pipe inserted. This was backfilled with clean sand and auger cuttings in the screened zone and then with bentonite to the surface. Each well was surveyed and water levels in each piezometer were logged hourly using capacitance probes (Dataflow-model 392, accuracy +/- 0.01 m).

All groundwater samples were collected from the *P. distichum* ecotone during 2001-02, while the water table was within the sulfuric horizons. This was a period of below average rainfall and receding backswamp water tables. Groundwater samples were extracted from the sulfuric horizons in freshly excavated, 0.05 m diameter unlined wells using a hand pump. The pH, Electrical Conductivity (EC), redox potential (ORP) and temperature were immediately measured using freshly calibrated portable field equipment (TPS 90FLMV). A minimum of two 250 ml sub-samples were collected in clean (acid rinsed, distilled water flushed) polyethylene bottles thoroughly pre-rinsed with the sample water a minimum of 4 times. Visible air bubbles were excluded prior to sealing the cap and samples placed in cold storage (~4^{o} C). One 250 ml sub-sample was analysed for titratable acidity to pH 5.5 (APHA 2310B - including the peroxide oxidation step) within 24 hrs of sample collection. One 250 ml sub-sample was selected for further chemical analysis, and analysed for total Fe and total Al (ICPAES - USEPA 6010), dissolved Fe and dissolved Al (0.45 µm filtration, ICPAES - USEPA 6010), Cl^- and SO_4^{2-} (Ion chromatography - AHPA 4110).

Results

Site management / groundwater conditions

The monitoring period was one of below average rainfall and receding groundwater tables. This provided a good opportunity to assess accumulation of acid solutes in surface soils. During the ~12 months of pasture monitoring there was very little difference in surface water management at the two sites and water tables at both sites were similar and were mostly below the ground surface (Fig. 2). There was one short floodgate opening event (September 2001) which caused surface re-flooding at Morans. However, the penstocks were opened allowing the water to drain back into the river and thus the effects upon the water table lasted several weeks only (Fig. 2). Figures 3 and 4 show examples of pasture cages located in the *P. distichum* ecotone at Morans and Sweenys backswamp respectively.

Pasture productivity

There were large differences in standing biomass between the two systems, particularly in the *P. distichum* ecotone (Fig. 5a). The *P. distichum* ecotone remained bare and scalded at Sweenys while a spring-summer flush occurred at Morans (Fig. 5a) resulting in an extreme difference in biomass / productivity. The standing biomass accumulation at Morans *P. distichum* ecotone averaged over the 6 month spring / summer flush (September to February) was about 1000 kg / ha month^{-1} (Fig. 5a).

Biomass differences in the *C. dactylon* ecotone were also evident, with Morans higher than Sweenys (Fig. 5b). The *C. dactylon* ecotone had higher dry matter yields than the *P. distichum* ecotone, though a substantial fraction of this was dead material (Fig. 6a). The proportion of green vegetative material (a measure of productivity) in both the *P. distichum* and *C. dactylon* ecotones displayed strong seasonality, with maximum growth and peak vegetative stage expectedly corresponding to the summer months (Fig. 6b).

The differences in standing biomass and seasonal productivity cannot be simply explained by short term water management during the period of study, as both sites are subject to similar rainfall (being less than 2 km apart) and experienced very similar relative groundwater levels. Large differences in the amount of surface organic matter accumulation were evident between the two sites. Morans had a 2-8 cm thick layer of decaying organic matter over the mineral soil surface in the *P. distichum* ecotone, whereas in the same ecotone at Sweenys the soil surface was bare with no organic layer during the entire monitoring period.

This difference in surface organic matter (itself a reflection of *long-term* differences in water and pasture management) is a critical factor affecting the biomass / productivity differences between the two sites. Surface organic matter accumulation plays a vitally important role in three interrelated processes affecting the toxicity of topsoil to plants in these ASS backswamp landscapes. These include;

- upward evaporative flux of shallow groundwater solutes (i.e. Minh *et al.* 1998).
- complexation of acidic metal cations with organic acids (i.e. Breemen 1993).
- reduction processes; reformation of sulfides, consumption and temporary storage of acidity.

Soils and groundwater

Both sites had comparable soil stratigraphy and displayed similar depths to the sulfidic horizon (Fig. 7). The chemical composition of sulfuric horizon groundwater was also very similar at both sites (Table 1), with pH values less than 4 and an EC > 10 dS m^{-1}. However, a substantial difference is the degree of upward evaporative flux of shallow groundwater solutes and accumulation of acidity near the soil surface (upper ~10 cm). This appears to be a major factor determining the productivity differences in the *P. distichum* ecotone between the two sites. Soil EC, chloride and sulfate profiles are characteristic of upward flux and surface accumulation particularly at the Sweenys site (Fig. 7). The concentration of solutes and acidity in near surface soils is significantly greater at Sweenys. This is a reflection of the lack of surface organic matter and the effect that organic matter and an actively transpiring vegetative cover has on attenuating upward evaporative flux from the capillary fringe to the soil surface.

The primary source of solutes and acidic ions accumulating in the surface soil is the shallow groundwater from the sulfuric horizons. The accumulation of solutes and acidic ions in surface soils at Sweenys creates a hostile environment for plant roots which explains why this ecotone remained bare during the study period (Fig.8). In addition to the substantial accumulation of chloride and sulfate ions, Sweenys surface soils also exhibited extensive accumulations (~9%) of amorphous Fe (III) oxides in the surface soils (Table 2). Enhanced surface accumulation of sulfide oxidation products, such as sulfate and amorphous Fe (III) oxides, at Sweenys is likely to influence sulfide reformation during wet periods and may increase the likelihood of H_2S or Fe^{2+} toxicity developing in the root zone after re-flooding (Breeman 1993; Lamers *et al*. 2002).

Discussion

It has become apparent during the course of this research that there is large variability both between and *within* what can be classified as 'wet' and 'dry' managed ASS backswamps; both in terms of pasture biomass and soil characteristics. For example, at Maloneys backswamp (see sub-project 2a), which is essentially a 'dry managed' system, the biomass in the ASS backswamp (a transitional *P. distichum* and *C. dactylon* ecotone) is *equivalent* to the mean of the *C. dactylon* ecotone at Morans (data not shown). The Maloneys site has had very low stocking rates for a considerable period (5 - 10 yrs) and as a result there is a large accumulation of surface organic matter (2 - 3.5 kg / m^2). Further, there has been no burning of the surface vegetation during this period whereas light surface burns are still practiced at Morans. While soil profiles at Maloneys are more acidic and have a shallower sulfide layer with greater sulfide concentrations (Fig. 7), the EC, chloride and sulfate profiles indicate a leached profile with substantially lower solute concentrations in near surface soils and limited upward accumulation compared to either the Morans or Sweenys backswamps (Fig. 7). The mean pasture biomass from both Maloneys and Morans shows some negative correlation with increasing near surface (0-10 cm) solute / acidity accumulations (Fig.9).

While Maloneys is a dry managed site, there other clearly other factors maintaining a lower topsoil toxicity and thus pasture biomass. High acid flux rates and leaching of solutes (see Sub-project 3b), low stocking rates and long term organic matter accumulation as well as different groundwater chemistry are all likely to be significant factors.

Conclusions

It is apparent there is a large degree of site variability in both soil and pasture biomass / seasonal productivity between ASS backswamps. The factors influencing soil toxicity and pasture biomass in drained ASS backswamps are highly complex and influenced by a wide range of interrelated variables. Further research is needed to improve current understanding.

While wetter management *can* encourage more surface organic matter accumulation over long periods and thereby attenuate upward evaporative flux and acid / solute accumulation processes in surface soil, this is does not occur in isolation to other management activities (i.e. grazing intensity / fire). Meaningful predictions of the likely changes in biomass based on altering an ASS backswamps water management strategy alone (i.e. a switch to wetter management) cannot be made in isolation from other management factors. This research suggests that *whole grazing system management* (i.e. stocking rates, seasonal spelling, fire) and antecedent soil / groundwater characteristics will have a large effect upon the grazing productivity of the system and cannot be separated from any predictive assessment. Ideally management needs to be based on an understanding of the key principles effecting biomass accumulation / productivity and off-site acidification impacts.

In some ASS backswamp systems a wetter management strategy is likely to improve standing biomass over time (i.e. Sweenys). However, gains made in surface organic matter accumulation can be *easily destroyed* by other management activities such as fire or overstocking. In other ASS backswamp systems it is possible that the biomass changes associated with wetter management may be more neutral, with a shift occurring in the dominant pasture species and the seasonality of production.

It is also clear from extension work carried out during this project that there are significant impediments to the broad scale adoption of wetter management strategies in ASS backswamps, which collectively create a lack of incentive to adopt change. These include;

- Increasing land fragmentation with many small holdings having minimal flood free land. This encourages landholders to run 'dry' systems with set stocking rates and no seasonal spelling.
- Preference for 'dry' managed systems.
- Access and fencing issues.

- Human and animal health concerns (i.e. mosquitoes).
- Cultural and social issues.

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Table 1. Chemical composition of sulfuric horizon groundwater in the *P. distichum* ecotone at the study sites. Data shown are means.

(All concentrations are mmol L^{-1}. Figures in brackets are standard deviation).

	Morans	Sweenys
pH	3.80 [0.29]	3.70 [0.21]
EC (dS m^{-1})	15.7 [2.7]	11.7 [1.7]
Chloride	73.0 [51.7]	74.1 [9.9]
Sulfate	67.6 [9.8]	58.1 [8.7]
Titratable acidity (H^+)	19.0 [6.0]	13.9 [12.9]
Dissolved Fe	6.8 [4.1]	2.9 [2.6]
Dissolved Al	1.7 [1.4]	2.4 [1.8]

Table 2. Chemical composition of iron-rich surface soil (0-2 cm) from a scald at Sweenys backswamp. Date collected 27/9/2001.

	Sweenys
Chloride (%)	0.86
Sulfate (%)	2.33
Oxalate extractable Fe (%)	9.1

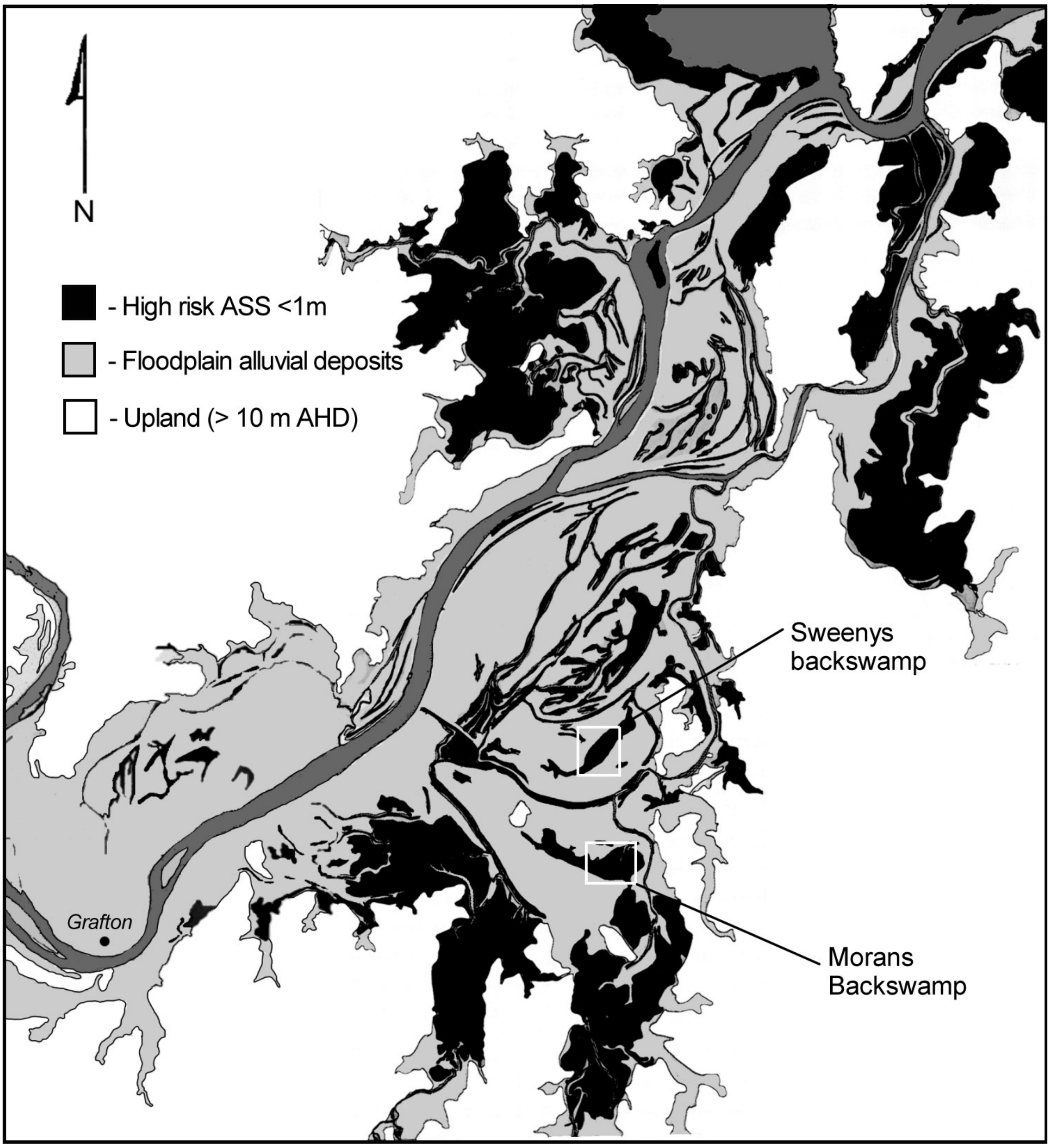

Fig. 1. Lower Clarence River floodplain and location of Sweenys and Morans ASS backswamp study sites.

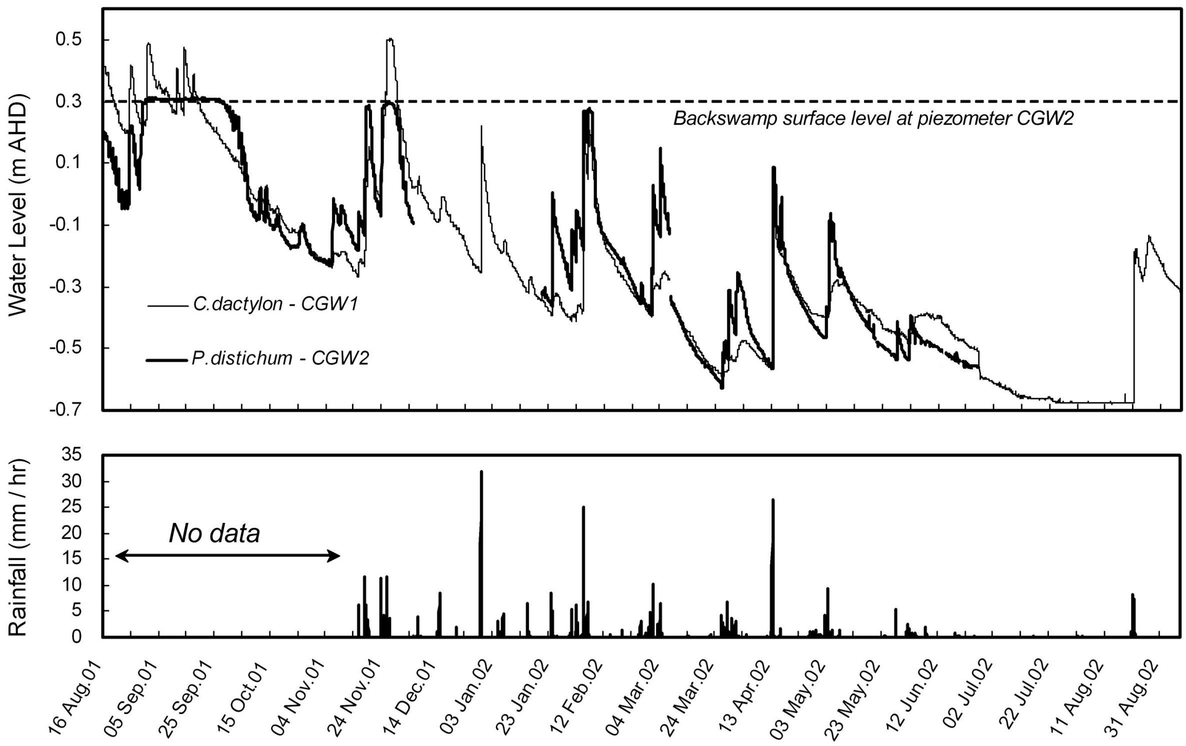

Fig. 2. Groundwater elevation data and rainfall at Morans study site from August 2001 to September 2002. Note this was a period of below average rainfall and receding water levels.

Fig. 3. Pasture cage in the *P. distichum* ecotone at Morans study site.

Fig. 4. Pasture cage in the *P. distichum* ecotone at Sweenys study site.

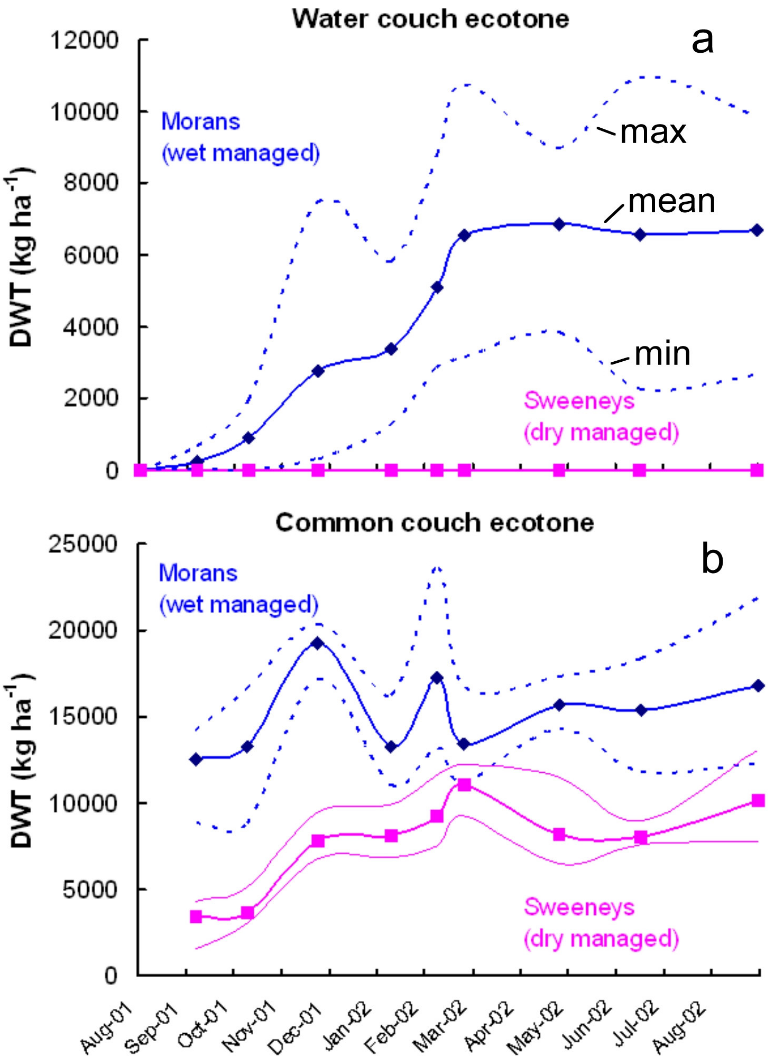

Fig. 5. Standing biomass comparison (DWT = dry weight) at Morans and Sweenys ASS backswamp in the a) water couch (*Paspalum distichum)* ecotone and b) common couch (*Cynodon dactylon*) ecotone during 2001-02.

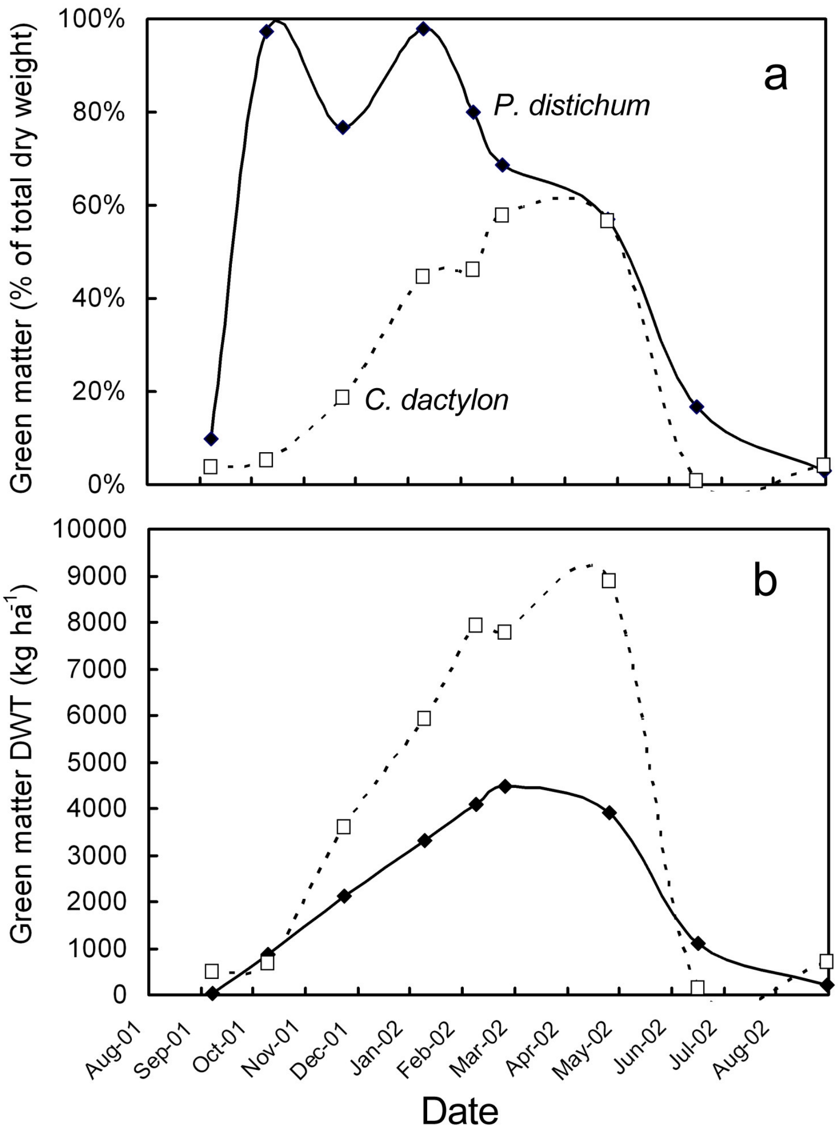

Fig. 6. Seasonal productivity changes in a) green matter as a % of dry weight and b) green matter total dry weight in the *P. distichum* and *C. dactyon* ecotones at Morans study site. Values shown are means of all pasture cages.

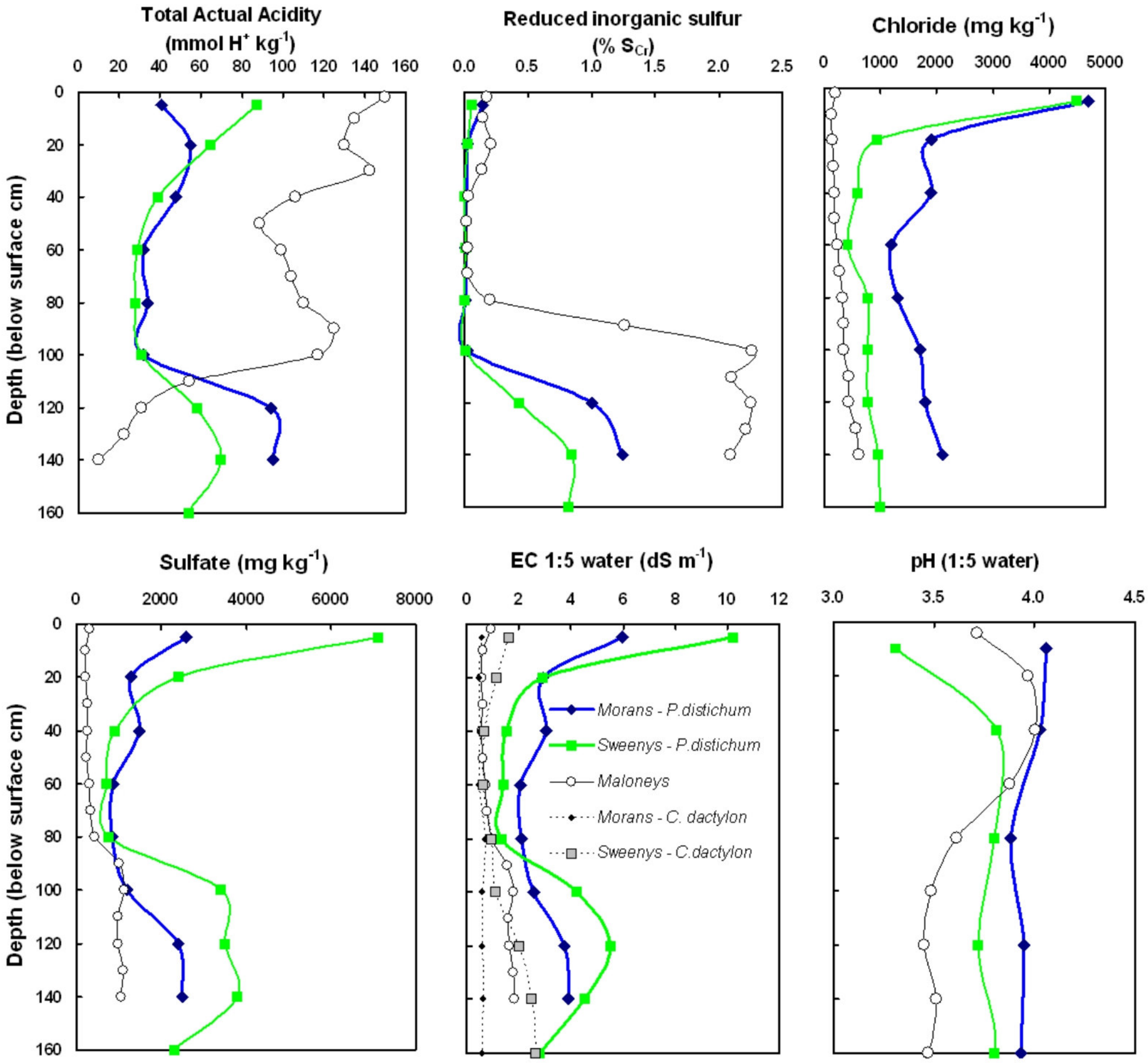

Fig. 7. Comparing the soil chemical characteristics with depth in the *P. distichum* ecotone at Morans, Sweenys and Maloneys backswamps. The EC (1:5) chart also shows data from the *C. dactylon* ecotone; note the much lower EC and lack of upward solute accumulation.

Fig. 8. Acidic surface scalding at Sweenys study site showing white salt efflorescence on the surface underlain by an Fe (III) rich layer. This creates a very hostile micro-environment for plant roots.

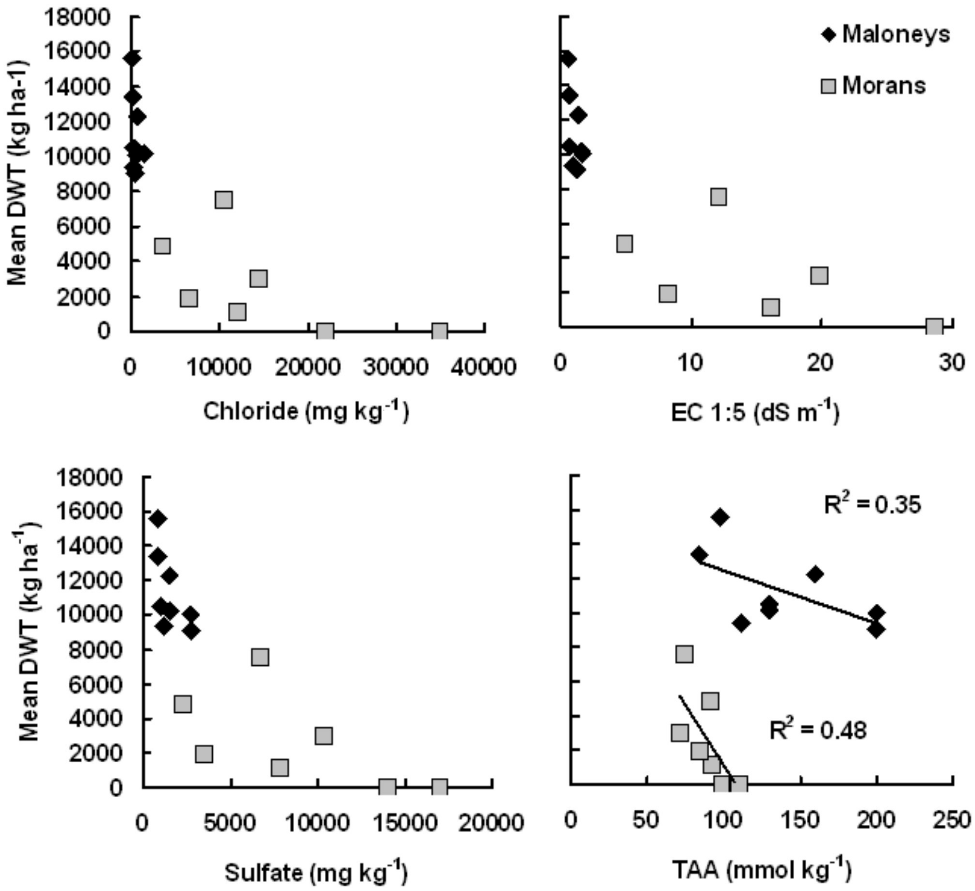

Fig. 9. Comparing mean pasture standing biomass (Mean DWT) and mean surface soil (0-10 cm) solute accumulations at Maloneys and Morans backswamps. Negative correlation is evident in all cases. Morans data based on *P. distichum* ecotone.