Australian Journal of Experimental Agriculture, 2001, **41**, 487–496

Pasture management in semi-arid tropical woodlands: regeneration of degraded pastures protected from grazing

J. G. McIvor

CSIRO Sustainable Ecosystems, 120 Meiers Road, Indooroopilly, Qld 4068, Australia; e-mail: john.mcivor@cse.csiro.au

Abstract. Regeneration of native and oversown pastures following exclusion of grazing was studied over 3 years on a fertile soil at Hillgrove, near Charters Towers, north-east Queensland. The pastures covered a wide range of initial conditions reflecting the grazing pressures they had been exposed to during 2 dry years before enclosure. Pasture measurements made before the exclusion of grazing (yield, botanical composition, basal area, ground cover, height, soil seed banks) were related by regression analysis to subsequent changes in site condition described by a site condition value, calculated from herbage yields and botanical composition, to determine suitable predictors of regeneration during resting from grazing.

The pastures recovered (increases in soil cover, grass basal area and the proportion of desirable species) under the generally favourable growing conditions during the period of enclosure although some plots, initially in poor condition, had not recovered after 3 years. There were only minor differences between the native and oversown pasture types in their recovery. Relative yields and site condition values were not affected by pasture type and botanical composition index values differed with pasture type in 1989 only.

The site condition values of both pasture types after the first year of enclosure were closely and positively related to all the pasture characteristics measured the previous year except for soil seed numbers in the native pastures. All characteristics could be used to predict site condition value and potential of the pasture to regenerate, and their merits are discussed. The proportion of desirable species in the pasture combined with level of ground cover is suggested as a useful means of predicting regeneration and potential for future grazing.

Introduction

There is growing concern about degradation in northern Australian grazing lands. In a recent survey, Tothill and Gillies (1992) found 44% had suffered some change, of which 12% was badly affected with severe soil deterioration and dominance of undesirable species. Most of the grazing land is native pasture and degeneration of these pastures includes the loss of palatable perennial grasses, soil deterioration and loss, and the invasion of undesirable species (less palatable grasses, herbaceous and woody weeds). The perennial grasses are the major source of herbage for animals and provide valuable ground cover to protect the soil surface so loss of these grasses has important implications for both animal production and soil erosion. Drought and heavy grazing, either singly or particularly in combination, can result in the death of perennial grasses.

Although native pastures have been retained in most of the northern Australian rangelands, introduced legumes and grasses have been sown on small but important areas. Such pastures have higher levels of animal production (Gillard and Winter 1984; Coates *et al.* 1997) but, like the native pastures they have replaced, they are also subject to deterioration and loss of productive potential. This loss is mainly due to the replacement of the more productive and higher quality sown species by native species and weeds. The area of sown pastures suffering such deterioration each year has been estimated at about 100000 ha (Walker 1991). The sown pastures support higher stocking rates than native pastures but they may also be damaged by heavy grazing particularly in dry times.

Spelling or resting pastures (i.e. exclusion of animals) is frequently suggested to allow pastures to regenerate to a productive, nutritious state with good ground cover. If spelling is to be recommended as a management practice we need to be able to predict whether pastures will regenerate naturally with spelling or whether some form of intervention (e.g. cultivation and seeding) will be necessary. McIvor and Gardener (1990) studied 20 native pastures near Collinsville that had been grazed to different degrees and measured their performance when they had been spelled for 1 year. They showed that basal area of the grasses was the best predictor of performance during a year of spelling.

Those investigations were expanded when dry conditions during 1987 and early 1988 (Table 1) at the ECOSSAT (Ecological Studies in the Semi-Arid Tropics) site at Hillgrove near Charters Towers provided an opportunity to (i) examine another set of native pastures; (ii) contrast the native pastures with a similar set of sown pastures; and

10.1071/EA00045 0816-1089/01/040487

(iii) follow regeneration for a longer period. Basal area is not a particularly useful tool for managers so ground cover was also included in this study as it is useful for predicting runoff and soil loss (McIvor *et al.* 1995).

Plots selected with a wide range of initial pasture condition were used to determine how condition changed during a 3-year period of enclosure (1989–91). The specific objectives were: (i) to describe the condition of pastures subjected to a range of grazing pressures during a dry period; (ii) to measure the regeneration of these pastures when unstocked during a period of higher rainfall; and (iii) to develop criteria that could be used to predict the capacity of overgrazed pastures to regenerate by relating pasture performance (yield and botanical composition) during the regeneration period to the initial pasture characteristics. Both native pastures and pastures oversown with introduced legumes and grasses were studied to determine if they responded differently.

Materials and methods

Location

The ECOSSAT plots were located on Hillgrove Station (19°40′S, 145°45′E) about 80 km north-west of Charters Towers. The average annual rainfall is 535 mm but annual totals have ranged from 128 to 1366 mm. The soil at Hillgrove is a fertile euchrozem (Gn3.12, Northcote 1979; eutrophic red ferrosol, Isbell 1996) with an extractable phosphorus level of 50 mg/kg in the surface soil. The native vegetation is open woodland with *Eucalyptus crebra* and *Corymbia erythrophloia* the dominant tree species, and *Bothriochloa ewartiana, Heteropogon contortus* and *Chrysopogon fallax* the dominant grasses. A full description of the site and environment at Hillgrove is given in McIvor *et al.* (1991).

The complete ECOSSAT site has 40 experimental paddocks consisting of various combinations of native and sown pastures, superphosphate application, tree killing, tree clearing and cultivation before sowing, and stocking rate (McIvor and Gardener 1995).

Experimental plots

Sixteen paddocks (8 native pastures and 8 oversown pastures) were selected. These were in a factorial combination of live or killed trees, and 4 stocking rates (0.1, 0.2, 0.33 and 0.5 steers/ha for the native pastures and 0.2, 0.33, 0.5 and 1.0 steers/ha for the oversown pastures). The trees had been killed in April 1982, and the stocking rates imposed from June 1984.

Three plots (each 8 by 8 m) were selected in each paddock in August 1988 to represent the range in pasture conditions present in the paddock. Based on visual appraisal an area in good condition (high yield, high cover, high basal area), an area in poor condition, and an area in medium or intermediate condition were selected. There was considerable overlap in the characteristics of the different condition plots in different paddocks, for example a good condition plot in a heavily grazed pasture could have lower yields, cover and basal area than a poor condition plot in a lightly grazed pasture. These plots were fenced to exclude cattle.

Initial measurements of vegetation

Measurements to describe the initial condition of the vegetation were made in September 1988. Herbage yield and botanical composition were estimated using the BOTANAL technique (Tothill *et al.* 1992). Visual ratings were made of the basal area of the perennial grasses and total ground cover on 30 quadrats (50 by 50 cm) in each plot. The ratings were converted to estimates using standard scales calibrated in a similar manner to that of Haydock and Shaw (1975). The basal area of the standard quadrats was determined using a point quadrat (Brown 1954), and the cover of the standard quadrats by determining the presence or absence of cover at 100 points on a photograph of the quadrat (McIvor *et al.* 1995). Pasture height was measured at 24 locations in each plot using a pasture height meter similar to that described by Castle (1976). Soil seed banks were measured in the good and poor condition plots in each paddock. One hundred cores (2.5 cm diameter by 10 cm deep) were taken from each plot and seed numbers determined using the techniques described by McIvor and Gardener (1994).

Pasture growth measurements

Estimates of yield and botanical composition were made at the end of the growing season in March 1989, May 1990 and April 1991. The plots were mowed to 10 cm in September 1988, October 1989 and September 1990 and the herbage removed. This would have removed some nutrients reducing the amount available for regrowth. However, this impact is unlikely to be significant during this short-term experiment on this fertile soil. Depending on plot yield, up to 20 kg nitrogen/ha and 2 kg phosphorus/ha could have been removed; these losses represent 1% of the total nitrogen and 3% of the extractable phosphorus in the surface soil (0–10 cm).

Site condition values

A site condition value based on pasture yield and botanical composition was calculated for each plot each year in a similar manner to that of McIvor and Gardener (1990). The mean yield of the 3 highest yielding plots was taken as an estimate of potential yield for that year and relative yields were calculated by expressing the herbage yield of each plot as a proportion of the potential yield with a maximum value of 1.0. Separate estimates of potential yield were made for the native and oversown pastures since the limiting factors could differ with pasture type, for example soil nitrogen may be more limiting for native pastures than legume-based pastures in a wet year. The contribution of botanical composition to the site condition value was assessed on the basis of the desirability (i.e. nutritive value and acceptability to animals) of the species in each pasture. Species were divided into 3 groups: legumes and all perennial grasses (except *Aristida* spp.) were considered desirable, annual grasses intermediate, and other species undesirable. The proportion of the herbage contributed by a species was multiplied by 1.0 for desirable species, by 0.5 for the intermediate species and by 0 for the undesirable species, and the products summed to give a botanical composition index between 0 and 1.0. The site condition value (0–1.0) is the product of the relative yield and botanical composition index values.

Meteorological data

Daily rainfall and evaporation were recorded at the site. All plots were within 1 km of the recording station. The simple water balance model WATBAL (Keig and McAlpine 1974) was used to calculate the water index of Fitzpatrick and Nix (1970). The water index is the ratio of predicted evapotranspiration to potential evapotranspiration and can range in value from 0 to 1.0. A value of 0 indicates no water is available for growth and a value of 1.0 indicates water is not limiting. Available water storage capacity of the soil was set at 150 mm and a potential evapotranspiration rate of 0.75 × (pan evaporation rate) was assumed.

Data analyses

Data were analysed using an analysis of variance for repeated measures procedure in Genstat 5 (Payne *et al.* 1988). The 4 treatment variables (pasture type, initial pasture condition, timber treatment and previous stocking rate) composed the subjects stratum where the 4-factor interaction was used as the error term. Since the stocking rates were different on the native and oversown pastures, a nested stocking rate within pasture term was used rather than a main effect stocking rate

Table 1. Monthly rainfall at Hillgrove during 1987–91 in comparison with long-term values

	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
1984	353	97	12	3	1	1	26	2	6	65	4	50	621
1985	37	49	55	36	26	46	51	0	0	127	76	61	564
1986	121	159	6	42	57	17	2	12	17	72	43	45	593
1987	107	31	91	8	21	23	6	2	2	12	35	83	420
1988	2	74	9	95	11	4	36	66	0	23	20	84	423
1989	46	117	60	136	56	42	46	19	1	10	85	98	715
1990	7	6	133	105	36	78	3	0	0	5	0	106	479
1991	336	338	6	5	34	1	0	1	0	0	50	104	875
Mean	134	110	88	29	18	18	11	7	7	17	36	71	546

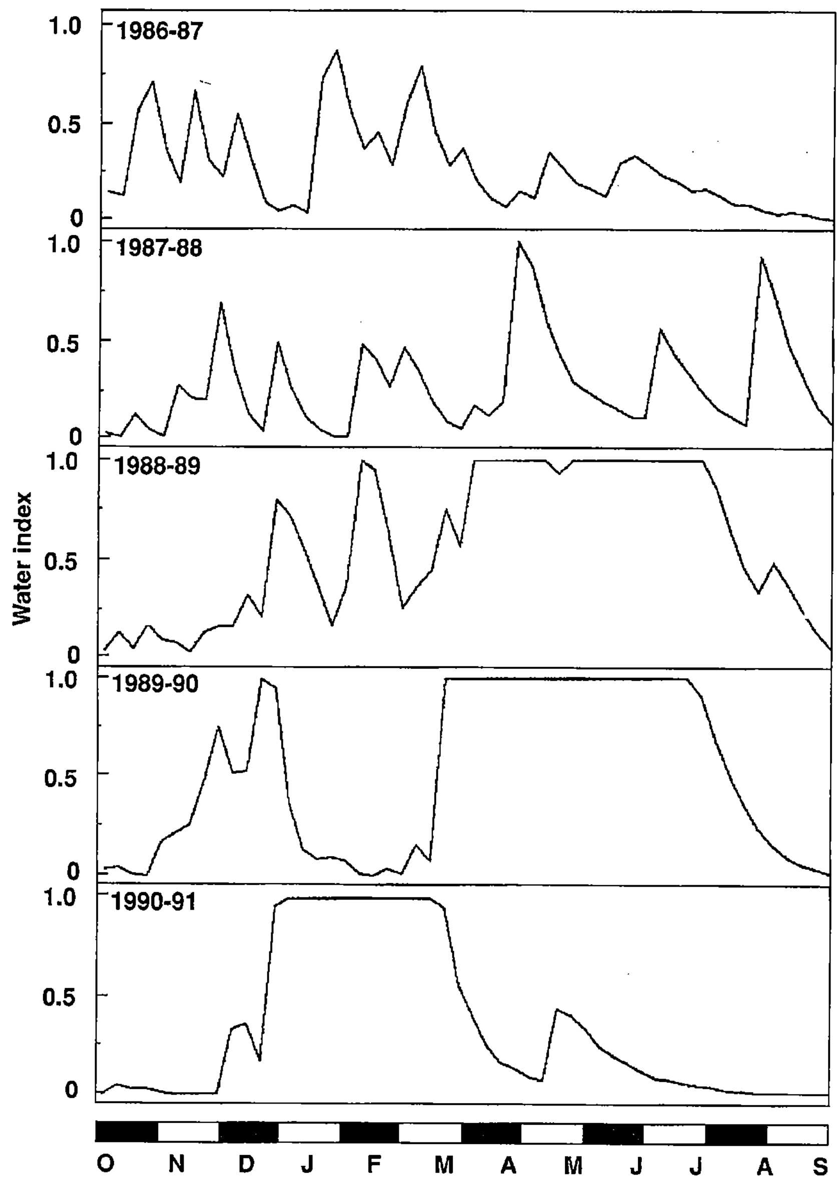

Figure 1. Weekly values of the water index of Fitzpatrick and Nix (1970) for 5 years at Hillgrove.

term. Even though the condition plots were nested within the other (pasture type, timber treatment, stocking rate) treatment combinations a factorial design was assumed. Because of this assumption, only the effects that were highly significant (P<0.01) are discussed in detail.

The site condition values for 1989 were plotted against the pasture characteristics measured in 1988 to determine suitable predictors of site condition value. Although linear regressions gave good fits for some predictors, asymptotic relationships were apparent for most characteristics. These were chosen and used for all predictors for 2 reasons. First, the asymptotic relationships always explained more of the variance than linear relationships (although the difference was sometimes small). Second, the linear relationships predicted site condition values >1.0 for high predictor values. An equation,

$$SCV = a + be^{kX}$$

where SCV is site condition value, X is pasture characteristic, and a, b and k are constants, was fitted using Genstat 5 (Payne *et al.* 1988). The pasture characteristics were herbage yield, pasture height, basal area, ground cover and soil seed banks for both pasture types, proportion of perennial grass for the native pastures, and proportion of perennial grass plus legume for the oversown pastures.

Results

Rainfall and growing conditions

Rainfall was below average in 1987 (Table 1) and conditions were particularly dry in early 1988 when only 85 mm fell during January–March compared with the long-term mean of 332 mm. However, this period was followed by 95 mm in April and further falls in July and August and above average rainfall in 1989. January–February 1990 were very dry but March–April falls were well above average. Conditions were very wet during late December 1990 to February 1991 when 780 mm fell (long-term mean = 315 mm). These variations in rainfall are reflected in the water index values shown in Figure 1. During 1986–87 and 1987–88 there were no occasions when the water index was 1.0 for 2 consecutive weeks. However, during the subsequent 3 years there were long periods when the water index maintained a value of 1.0.

Using the methods of McCown (1973), the growth weeks for the 5 seasons (1986–87 to 1990–91) were estimated to be 13, 4, 17, 15 and 17 weeks compared with a median value of 14 weeks. Thus growing conditions were generally above average during the 3 years the pastures were unstocked although conditions were very poor in January–February 1990.

Initial characteristics

The range of values and individual treatment means are shown in Table 2. The plots varied from almost bare ground to dense stands of perennial grass (native pastures) or mixed grass–legume (oversown pastures). As pasture condition declined herbage yield, perennial grass content, basal area, cover and height all declined. There were large differences between the timber treatment plots; those with killed trees had higher herbage yields, more perennial grass, greater basal area, higher cover and were taller. Stocking rate also

Table 2. Initial pasture characteristics (mean ± s.e.) of native and oversown pasture plots during September 1988 following two poor growing seasons

The characteristics were determined when the plots were enclosed; the minimum and maximum values are for all plots and the comparisons of treatments (pasture type, pasture condition, timber treatment and stocking rate) are for plots grazed at 0.2, 0.33 and 0.5 steers/ha only to allow comparison of native and oversown pastures

Treatment	Herbage yield (kg/ha)	Stylo[A] (%)	Perennial grass Native (%)	Perennial grass Sown (%)	Basal area (%)	Ground cover (%)	Herbage height (cm)	No. of stylo seeds[A]	No. of perennial grass seeds	Total no. of seeds
Range										
Minimum	10	0	0	0	0	8	0	0	0	190
Maximum	5680	57	99	61	5.9	90	24.9	220	650	1560
Pasture type										
Native	1190 ± 268	—	88 ± 3	0 ± 0	2.4 ± 0.4	45 ± 5	8.5 ± 1.8	—	200 ± 52	580 ± 82
Oversown	1010 ± 229	23 ± 4	51 ± 6	14 ± 5	1.7 ± 0.3	43 ± 5	7.3 ± 1.6	50 ± 18	230 ± 59	790 ± 107
Pasture condition										
Good	1720 ± 393	29 ± 6	77 ± 7	5 ± 4	3.1 ± 0.4	64 ± 5	11.6 ± 2.5	80 ± 30	240 ± 58	760 ± 105
Medium	960 ± 210	26 ± 7	73 ± 7	8 ± 5	1.9 ± 0.4	40 ± 5	7.7 ± 1.7	n.d.	n.d.	n.d.
Poor	620 ± 182	14 ± 4	59 ± 9	9 ± 9	1.2 ± 0.4	29 ± 5	4.4 ± 1.2	20 ± 10	190 ± 53	620 ± 91
Timber treatment										
Live trees	340 ± 64	28 ± 6	65 ± 6	1 ± 1	1.0 ± 0.2	30 ± 4	2.5 ± 0.5	40 ± 15	70 ± 20	540 ± 81
Killed trees	1860 ± 230	18 ± 4	74 ± 6	13 ± 5	3.1 ± 0.3	58 ± 4	13.3 ± 1.5	60 ± 34	360 ± 45	840 ± 99
Stocking rate (steers/ha)										
0.2	1210 ± 306	17 ± 4	80 ± 4	3 ± 1	2.2 ± 0.4	48 ± 7	9.5 ± 2.2	30 ± 19	170 ± 40	630 ± 152
0.33	1360 ± 370	25 ± 2	73 ± 6	4 ± 2	2.3 ± 0.4	46 ± 7	9.2 ± 2.3	90 ± 47	230 ± 75	520 ± 97
0.5	730 ± 196	28 ± 10	56 ± 9	14 ± 7	1.7 ± 0.5	39 ± 6	5.0 ± 1.3	30 ± 19	240 ± 84	910 ± 58

[A]Oversown plots only. n.d., not determined.

influenced pasture characteristics with herbage yield, proportion of perennial grass, basal area, cover and height all declining at higher stocking rates, particularly pasture yield and height. On the oversown pastures, plots in poor condition had lower legume contents than plots in good or medium condition. The seed bank numbers were low in all pastures. On average the soils contained 710 seeds/m^2 including 210 perennial grass seeds.

Changes during exclosure

Herbage yields. Mean herbage yields increased each year during the regeneration period from 1330 kg/ha in 1989 to 4590 kg/ha in 1991 (Table 3). Both pasture types had similar yields in 1989 but the native pastures were higher yielding in 1990 and the oversown pastures in 1991. Initial condition affected yields — the poor condition plots were lower yielding than the good condition plots in all years with the medium condition plots producing intermediate yields. Plots with live trees were lower yielding than plots with killed trees in 1989 and 1990 but timber treatment had no effect on yields in 1991.

Relative yields. Relative yields also increased with time for all treatments (Table 4) with no differences between the native and oversown pastures. In 1989 and 1990 the plots with live trees had lower relative yields than plots with killed trees, but in 1991 there were no differences between the 2 timber treatments. The poor initial condition plots had much lower relative yields in 1989 and although the differences decreased with time, the relative yields of the poor initial condition plots were still lower in 1991. Previous stocking rate effects on relative yield were small and variable with a tendency for relative yield on the oversown plots to be lower where the stocking rates had been high before enclosure.

Table 3. Herbage yields (kg DM/ha) of native and oversown pasture plots after 1, 2 or 3 years without grazing in relation to initial pasture condition, timber treatment and stocking rate

	1989	1990	1991	Mean
Year (main effect: P<0.001)				
	1330	3880	4590	3270
Pasture type (main effect: P = 0.378; interaction: P<0.001)[A]				
Native	1300	4240	4000	3180
Oversown	1360	3510	5180	3350
Pasture condition (main effect: P<0.001; interaction: P = 0.187)				
Good	1940	4840	5280	4020
Medium	1330	3920	4460	3240
Poor	730	2870	4030	2540
Timber treatment (main effect: P = 0.025; interaction: P<0.001)				
Live	890	3340	4860	3030
Killed	1780	4410	4320	3500
Pasture and stocking rate (main effect: P = 0.381; interaction: P = 0.005)				
0.1 steers/ha				
Native	1310	4340	4000	3220
Oversown	—	—	—	—
0.2 steers/ha				
Native	1380	4430	4160	3320
Oversown	1160	3980	5070	3400
0.33 steers/ha				
Native	1200	3390	4130	2910
Oversown	1280	4120	6000	3800
0.5 steers/ha				
Native	1320	4810	3700	3280
Oversown	1470	2220	5130	2940
1.0 steers/ha				
Native	—	—	—	—
Oversown	1550	3700	4540	3260

[A]Probabilities refer to the significance of the *F*-ratio in the analysis of variance for the treatment main effect and treatment × year interaction.

Table 4. Relative yields (pasture yield as a proportion of the estimated potential yield) of native and oversown pasture plots after 1, 2 or 3 years without grazing in relation to initial pasture condition, timber treatment and stocking rate

Values range from 0 (low) to 1.0 (high)

	1989	1990	1991	Mean
Year (main effect: P<0.001)				
	0.58	0.66	0.76	0.67
Pasture type (main effect: P = 0.245; interaction: P = 0.604)[A]				
Native	0.57	0.63	0.75	0.65
Oversown	0.60	0.68	0.77	0.68
Pasture condition (main effect: P<0.001; interaction: P<0.004)				
Good	0.76	0.78	0.87	0.80
Medium	0.64	0.68	0.74	0.69
Poor	0.35	0.51	0.67	0.51
Timber treatment (main effect: P<0.001; interaction: P<0.001)				
Live	0.42	0.57	0.79	0.59
Killed	0.74	0.74	0.73	0.74
Pasture and stocking rate (main effect: P = 0.027; interaction: P = 0.009)				
0.1 steers/ha				
Native	0.56	0.63	0.75	0.65
Oversown	—	—	—	—
0.2 steers/ha				
Native	0.60	0.66	0.78	0.68
Oversown	0.60	0.82	0.75	0.72
0.33 steers/ha				
Native	0.53	0.51	0.79	0.61
Oversown	0.68	0.84	0.89	0.80
0.5 steers/ha				
Native	0.58	0.72	0.71	0.67
Oversown	0.58	0.46	0.76	0.60
1.0 steers/ha				
Native	—	—	—	—
Oversown	0.54	0.63	0.67	0.61

[A]Probabilities refer to the significance of the *F*-ratio in the analysis of variance for the treatment main effect and treatment × year interaction.

Botanical composition index. The botanical composition index increased with time for all pastures, timber treatments and initial conditions (Table 5). The native pastures had higher values than oversown pastures in 1989 but there were no significant differences between pastures in later years. Initial condition always affected the botanical composition index but the effects decreased with time and the initially good and medium condition plots were similar in 1991. Plots with live trees always had lower indices than plots with killed trees but the differences decreased with time. Previous stocking rate had little impact on the botanical composition of the native pastures, but the botanical composition index was lower for plots with high previous stocking rates for the oversown pastures in 1989 although the effect decreased with time and values were similar in 1991.

Table 5. Botanical composition indices for native and oversown pasture plots after 1, 2 or 3 years without grazing in relation to initial pasture condition, timber treatment and stocking rate

Values range from 0 (poor) to 1.0 (good)

	1989	1990	1991	Mean
Year (main effect: $P<0.001$)				
	0.81	0.91	0.96	0.89
Pasture type (main effect: $P = 0.357$; interaction: $P<0.001$)[A]				
Native	0.85	0.91	0.94	0.90
Oversown	0.77	0.91	0.98	0.89
Pasture condition (main effect: $P<0.001$; interaction: $P<0.001$)				
Good	0.90	0.97	0.98	0.95
Medium	0.85	0.94	0.99	0.92
Poor	0.67	0.83	0.91	0.81
Timber treatment (main effect: $P<0.001$; interaction: $P<0.001$)				
Live	0.71	0.87	0.94	0.84
Killed	0.91	0.95	0.98	0.95
Pasture and stocking rate (main effect: $P = 0.009$; interaction: $P = 0.062$)				
0.1 steers/ha				
Native	0.90	0.91	0.90	0.90
Oversown	—	—	—	—
0.2 steers/ha				
Native	0.80	0.90	0.94	0.88
Oversown	0.85	0.94	0.99	0.93
0.33 steers/ha				
Native	0.87	0.93	0.95	0.92
Oversown	0.82	0.94	0.99	0.92
0.5 steers/ha				
Native	0.82	0.91	0.97	0.90
Oversown	0.75	0.92	0.99	0.89
1.0 steers/ha				
Native	—	—	—	—
Oversown	0.65	0.86	0.96	0.82

[A]Probabilities refer to the significance of the F-ratio in the analysis of variance for the treatment main effect and treatment × year interaction.

Site condition values. The site condition values increased with time with no differences between pastures (Table 6). The plots with killed trees had higher values than those with live trees in 1989 and 1990 but the difference was not significant in 1991. The site condition values increased from poor to medium to good initial condition in all years although the differences decreased with time. The effects of previous stocking rate were variable and small.

Relationships between site condition values and initial pasture characteristics

Native pastures. The site condition values for 1989 are plotted against pasture characteristics measured in 1988 in Figure 2. Herbage yield, the proportion of perennial grass, height, basal area and cover all had highly significant ($P<0.001$) relationships with site condition value and the

Table 6. Site condition values of native and oversown pasture plots after 1, 2 or 3 years without grazing in relation to initial pasture condition, timber treatment and stocking rate

Values range from 0 (poor) to 1.0 (good)

	1989	1990	1991	Mean
Year (main effect: $P<0.001$)				
	0.51	0.62	0.73	0.62
Pasture type (main effect: $P = 0.341$; interaction: $P = 0.343$)[A]				
Native	0.52	0.59	0.71	0.61
Oversown	0.50	0.64	0.75	0.63
Pasture condition (main effect: $P<0.001$; interaction: $P = 0.078$)				
Good	0.69	0.75	0.85	0.77
Medium	0.54	0.64	0.73	0.64
Poor	0.29	0.45	0.62	0.45
Timber treatment (main effect: $P<0.001$; interaction: $P<0.001$)				
Live	0.34	0.52	0.75	0.54
Killed	0.68	0.71	0.71	0.70
Pasture and stocking rate (main effect: $P = 0.034$; interaction: $P = 0.043$)				
0.1 steers/ha				
Native	0.53	0.61	0.68	0.61
Oversown	—	—	—	—
0.2 steers/ha				
Native	0.53	0.61	0.74	0.63
Oversown	0.49	0.77	0.74	0.67
0.33 steers/ha				
Native	0.50	0.48	0.75	0.58
Oversown	0.59	0.79	0.88	0.75
0.5 steers/ha				
Native	0.51	0.66	0.69	0.62
Oversown	0.50	0.44	0.75	0.57
1.0 steers/ha				
Native	—	—	—	—
Oversown	0.42	0.57	0.64	0.55

[A]Probabilities refer to the significance of the F-ratio in the analysis of variance for the treatment main effect and treatment × year interaction.

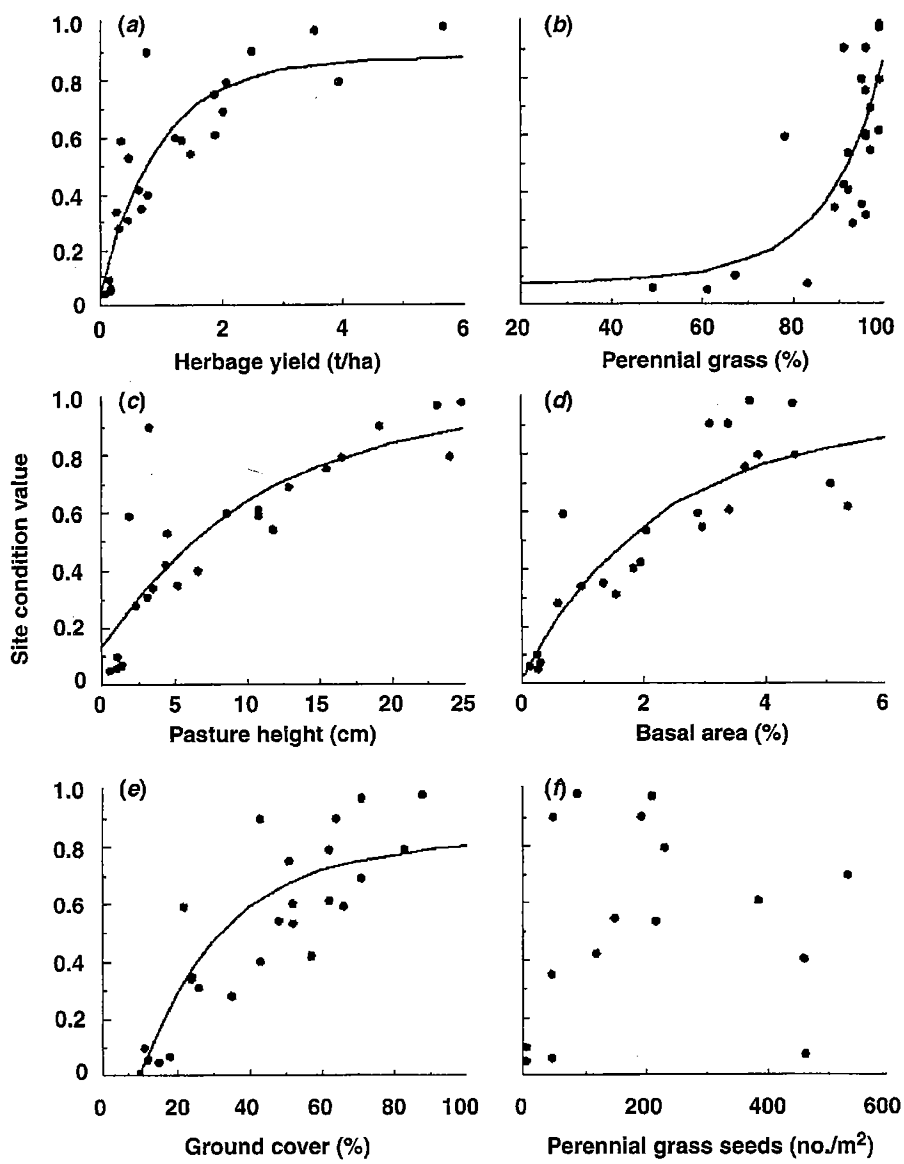

Figure 2. The relationships between site condition values (SCV) in 1989 and initial pasture characteristics measured in 1988 for native pasture plots. The relationships are between site condition value and (*a*) herbage yield (t/ha), (*b*) perennial grass (%), (*c*) pasture height (cm), (*d*) basal area (%), (*e*) ground cover (%) and (*f*) number of perennial grass seeds/m^2.

relationships explained 51–75% of the variance. All 5 characteristics were significantly (P<0.01) correlated with each other. There was no relationship between site condition value and the number of perennial grass seeds.

Oversown pastures. The site condition values in 1989 are plotted against pasture characteristics measured in 1988 in Figure 3. All 6 pasture characteristics had highly significant (P<0.001) relationships with site condition value with the relationships explaining 58–82% of the variance.

Discussion

Selecting plots with contrasting initial conditions in pastures with different previous managements (timber treatment, stocking rate, oversowing) gave a wide range of plots to study regeneration. There was considerable recovery (increases in soil cover, grass basal area and the proportion of desirable species) under the generally favourable conditions during the period of enclosure. The minimum site condition value increased from 0.01 in 1989 to 0.06 and 0.29 in 1990

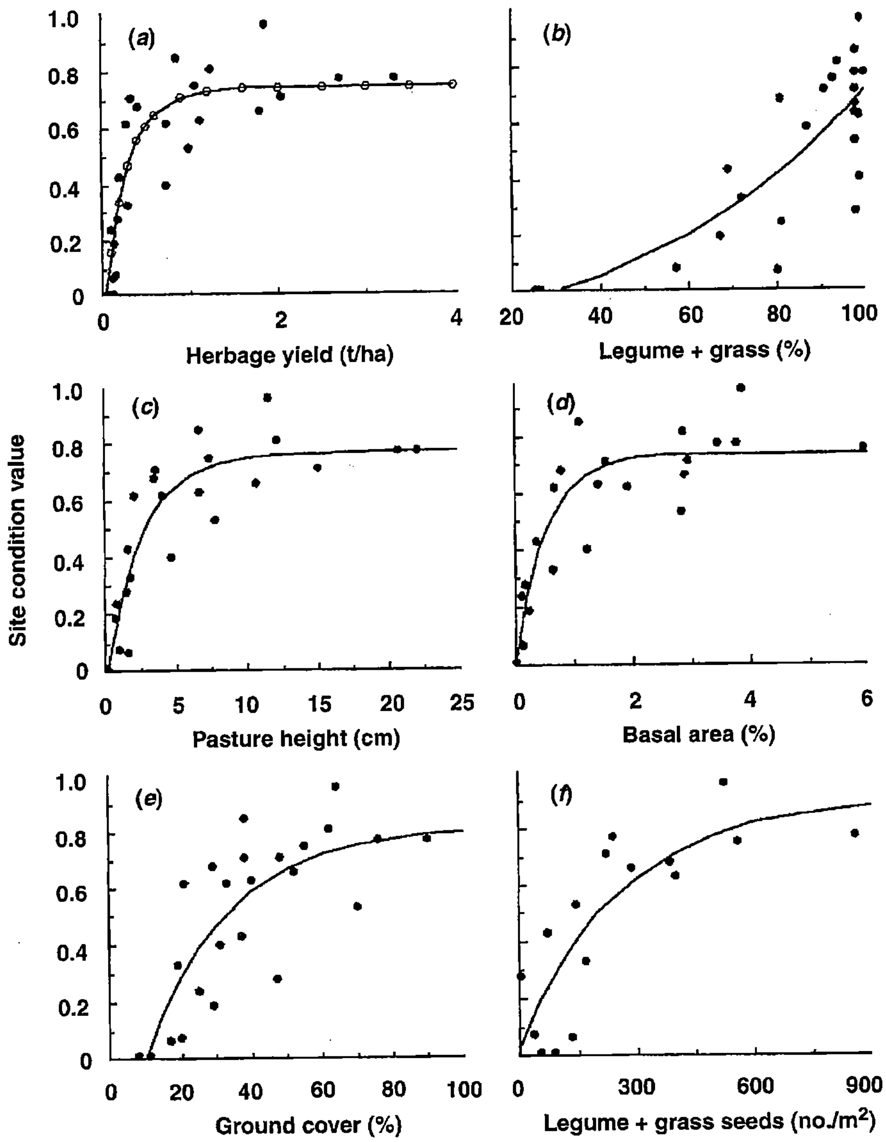

Figure 3. The relationships between site condition values (SCV) in 1989 and initial pasture characteristics measured in 1988 for oversown pasture plots. The relationships are between site condition value and (*a*) herbage yield (t/ha), (*b*) legume plus perennial grass (%), (*c*) pasture height (cm), (*d*) basal area (%), (*e*) ground cover (%) and (*f*) number of legume and perennial grass seeds/m^2.

and 1991, respectively. The prolonged wet conditions in 1991 were especially favourable for plant establishment. On bare plots where the soil surface was dry most of the time in previous years due to high runoff and low infiltration with the low cover, the soil remained wet for a prolonged period and plants established and grew well. For example, one oversown pasture plot in poor initial condition that had only 11% cover, 10 kg/ha of herbage and 26% perennial grass when selected in 1988 and was only slightly improved in 1989 (site condition value is 0.01) and 1990 (site condition value is 0.06), had a herbage yield of more than 5 t/ha comprising 80% perennial grass (mainly *Cenchrus ciliaris*), 93% cover and a site condition value of 0.77 in 1991.

Even with the generally favourable growing conditions and on the fertile soil at Hillgrove not all the plots had regenerated well after 3 years; in 1991, the site condition value remained below 0.50 for 5 of the 48 plots. These 5 plots were all initially in poor condition and included 4 native and one oversown plot. Generally the low site condition values were due to low herbage yields rather than to poor species composition; one native pasture plot remained dominated by annual grasses and dicots but the other 4 plots had botanical composition indices above 0.75, whereas the relative yields of the five plots ranged from 0.43 to 0.61. These results demonstrate that when pasture condition is reduced to a low level subsequent pasture performance can be reduced for a number of years. On less fertile soils and with less favourable conditions, the reductions are likely to be greater than those measured in this experiment.

The period of enclosure coincided with a period when the growing conditions were much more favourable than those immediately before enclosure of the plots — there were an average of 8.5 growth weeks per year in 1987 and 1988 compared with 16.3 growth weeks per year during 1989–91. This raises the question of whether the recovery was due to enclosure or the improved growing conditions. This question cannot be answered from this data set as no comparable measurements were made on similar plots where grazing continued. However, comparison of measurements (yield and botanical composition) in the paddocks around the enclosure plots with results from the medium condition plots suggest enclosure was important. Site condition values can be calculated for the paddocks using similar methods to those used for the enclosure plots. Although there was some improvement in site condition values of the heavily grazed paddocks during 1989–91, the values remained below those for the medium condition plots. The mean site condition value for the 4 most heavily grazed pastures was 0.13, 0.30 and 0.45 in 1989, 1990 and 1991 compared with values of 0.33, 0.52 and 0.79 for the medium condition enclosures in these pastures.

There were only minor differences between the native and oversown plots in their recovery under exclosure. Relative yields and site condition values were not affected by pasture type and botanical composition index values differed with pasture type in 1989 only.

The site condition values of both pasture types after the first year of enclosure were significantly related to all the pasture characteristics measured the previous year except for soil seed numbers in the native pastures. The asymptotic relationships explained 51–82% of the variation, and although the equations are specific to this experiment, they demonstrate how the pasture characteristics could be used to predict future site condition values.

Practical implications

All characteristics except soil seed levels in the native pastures could be used as predictors but they vary in their suitability for use in pasture management. For routine use, a desirable characteristic will be simple, cheap and quick to measure or estimate, and will not need detailed technical knowledge and experience or special equipment to use. Although soil seed banks are useful for interpreting pasture changes their assessment is too costly and time consuming for management use. Basal area explained the greatest proportion of the variance in both this and an earlier study (McIvor and Gardener 1990), but basal area is difficult to estimate reliably over a range of conditions, especially for inexperienced operators. Pasture height can be measured simply although it may be time consuming to collect sufficient measurements for an accurate estimate. Yield can be estimated against photographic standards such as those of Partridge (1995).

Of the characteristics measured in this experiment, ground cover and the proportion of desirable species in the pasture are the 2 measures likely to be most useful. They are both easy and quick to estimate and can be used routinely. If these characteristics are to be used to make decisions on pasture spelling then thresholds need to be established to discriminate between pastures that can regenerate with spelling and those that cannot. What values of these characteristics should be used? I suggest 70% for the proportion of desirable species and 40% for ground cover. Jones *et al.* (1995) found green panic (*Panicum maximum* var. *trichoglume*) pastures with less than 70% sown species were likely to deteriorate while Tothill and Gillies (1992) in their assessment of the pasture lands of northern Australia used 75% desirable species as the divide between pastures which would be sustainable under existing management, and those requiring management change (e.g. spelling) for rehabilitation. It can be seen in Figures 2*b* and 3*b* that when the proportion of desirable species was <70% the site condition values were all low; above this level they covered a wide range. Ground cover levels are closely related to runoff and soil loss and a number of studies have shown that runoff and soil loss increase rapidly when the cover drops below 40% (McIvor *et al.* 1995).

Using a combination of 70% desirable species plus 40% ground cover, 23 of the 48 plots were below this threshold. If an acceptable level of regeneration is defined as a site condition value of 0.50 (e.g. a pasture with about 70% of potential yield and 70% desirable species), then 17 of these 23 plots did not regenerate successfully (i.e. they had site condition values below 0.50). Similarly, 22 of the 25 plots above the threshold had site condition values above 0.50 (i.e. the success or failure of regeneration was correctly predicted for 39 plots or 81% of the total).

Successful regeneration will depend on growing conditions. The growing conditions during enclosure in this experiment were undoubtedly favourable and regeneration would most likely be slower with poorer growing conditions. However, the use of pasture characteristics should enable the pastures to be ranked in terms of recovery potential and the actual recovery will then be determined by the growing conditions experienced.

Acknowledgments

I gratefully acknowledge the late Dr C. J. Gardener for his contributions to experimental design and data collection, Mr T. H. Mann for the use of land, Dr P. N. Jones for statistical advice and assistance with data analyses, and Messrs P. E. J. Allen, W. A. Beyer and L. V. Whiteman for technical assistance.

References

Brown D (1954) 'Methods of surveying and measuring vegetation.' Commonwealth Bureau of Pastures and Field Crops Bulletin 42, Reading, UK.

Castle ME (1976) A simple disc instrument for estimating herbage yield. *Journal of the British Grassland Society* **31**, 37–40.

Coates DB, Miller CP, Hendricksen RE, Jones RJ (1997) Stability and productivity of *Stylosanthes* pastures in Australia. II. Animal production from *Stylosanthes* pastures. *Tropical Grasslands* **31**, 494–502.

Fitzpatrick EA, Nix HA (1970). The climatic factor in Australian grassland ecology. In 'Australian grasslands'. (Ed. RM Moore) pp. 3–26. (Australian National University Press: Canberra)

Gillard P, Winter WH (1984) Animal production from *Stylosanthes* based pastures in Australia. In 'The biology and agronomy of *Stylosanthes*'. (Eds HM Stace, LA Edye) pp. 405–432. (Academic Press: Sydney)

Haydock KP, Shaw NH (1975) The comparative yield method for estimating dry matter yield of pasture. *Australian Journal of Experimental Agriculture and Animal Husbandry* **15**, 663–670.

Isbell RF (1996) 'The Australian soil classification.' (CSIRO: Melbourne)

Jones RM, McDonald CK, Silvey MW (1995) Permanent pastures on a brigalow soil: the effect of nitrogen fertiliser and stocking rate on pastures and liveweight gain. *Tropical Grasslands* **29**, 193–209.

Keig G, McAlpine JR (1974) 'WATBAL: a computer system for the estimation and analysis of soil moisture regimes from simple climatic data.' CSIRO Division of Land Use Research Technical Memorandum No.74/4, Canberra.

McCown RL (1973) An evaluation of the influence of available soil water storage capacity on growing season length and yield of tropical pastures using simple water balance models. *Agricultural Meteorology* **11**, 53–63.

McIvor JG, Gardener CJ (1990) Soil and vegetation characteristics of dry tropical rangelands for predicting pasture regeneration in exclosures. *Proceedings of the Ecological Society of Australia* **16**, 273–277.

McIvor JG, Gardener CJ (1994) Soil seed banks in native pasture communities in northeastern Australia. *Australian Journal of Experimental Agriculture* **34**, 1113–1119.

McIvor J.G, Gardener CJ (1995) Pasture management in semi-arid tropical woodlands: effects on herbage yields and botanical composition. *Australian Journal of Experimental Agriculture* **35**, 705–715.

McIvor JG, Gardener CJ, Spain AV (1991) 'A description of the ECOSSAT experimental site at Hillgrove near Charters Towers, north Queensland.' CSIRO Australia Tropical Agronomy Technical Memorandum No. 70, Brisbane.

McIvor JG, Williams J, Gardener CJ (1995) Pasture management influences runoff and soil loss in the semi-arid tropics. *Australian Journal of Experimental Agriculture* **35**, 55–65.

Northcote KH (1979) 'A factual key for the recognition of Australian soils (4th edn).' (Rellim Technical Publications: Glenside)

Partridge IJ (1995) 'Managing northern speargrass: a graziers guide.' Queensland Department of Primary Industries Information Series Q195013, Brisbane.

Payne R.W, Lane PW, Ainsley AE, Bicknell KE, Digby PGN, Harding SA, Leech LK, Simpson HR, Todd AD, Verrier PJ, White RP (1988) 'GENSTAT 5 reference manual.' (Clarendon Press: Oxford)

Tothill JC, Gillies C (1992) 'The pasture lands of northern Australia.' Tropical Grassland Society of Australia Occasional Publication No. 5, Brisbane.

Tothill JC, Hargreaves JNG, Jones RM, McDonald CK (1992) 'BOTANAL — a comprehensive sampling and computing procedure for estimating pasture yield and composition. 1. Field sampling.' CSIRO Division of Tropical Crops and Pastures Tropical Agronomy Technical Memorandum No. 78, Brisbane.

Walker B (1991) Sustaining tropical pastures — summative address. *Tropical Grasslands* **25**, 219–223.

Received 7 March 2000, accepted 23 January 2001