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PATTERN OF DISTRIBUTION OF TOWNSVILLE STYLO, ANNUAL GRASSES AND PERENNIAL GRASSES IN RELATION TO SOIL VARIATION

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SUMMARY

The patterns of variation of soil conditions and vegetation were mapped on a mosaic area (4 ha) of solodized-solonetz and solodic soils in a seasonally dry tropical climate. The soil variables measured included: topography, available P, depth of A horizon, pH, basic exchangeable cations and the total soluble salts profile. Vegetation attributes included the total herbage yield and yield of perennial grasses, annual grasses, Townsville stylo and forbs.

Correlations between soil attributes, between vegetation attributes and between soil and vegetation attributes were calculated.

Only the total soluble salts profile accounted for a significant amount of the variation in vegetation attributes. Since the salt profile is known to be dependent upon the normal depth of wetting in the B horizon, it is concluded that the pattern of perennial grass distribution was determined primarily by variation in subsoil permeability, i.e. water storage capacity.

The yield of other vegetation components were negatively correlated with the perennial grass component, and it is concluded that the edaphic factors influence these components mainly indirectly via competition with the taller growing perennial grasses.

INTRODUCTION

Pastures of the Townsville-Burdekin region of northern Queensland consist primarily of native perennial and annual grasses with variable amounts of Townsville stylo (*Stylosanthes humilis* H.B.K.), a naturalized annual legume (Michell & Wood 1970). The legume component is an important determinant of animal production (Shaw & 't Mannetje 1970; Winks *et al.* 1974), but the magnitude of this legume contribution varies greatly in time and space. Causes of this variation include both management (Ritson, Edye & Robinson 1971; Woods & Dance 1970; Jones 1968) and physical environmental factors. The effects of climate and soil on the potential contribution of Townsville stylo on a continental scale has been considered by Begg (1972). Torssell (1973) has described the small scale pattern in Townsville stylo-annual grass pastures in relation to variation in microtopography. The present paper describes patterns in Townsville stylo-perennial grass-annual grass vegetation in relation to local soil variation.

The soils of the Townsville-Burdekin region have been described and mapped at various scales (Hubble & Thompson 1953; Isbell & Murtha 1970; Murtha 1975). Solodized-solonetz and solodic soils (Stace *et al.* 1968) are dominant over large areas, often in mosaic distributions. These soils are characterized morphologically by a thin sandy loam to clay loam A_1 horizon and a strongly bleached A_2 horizon abruptly overlying generally tough clay subsoils. Physically, this group of soils is characterized by impeded subsoil drainage. Other studies (McCown, Murtha & Smith 1976) have shown that the depth to which water permeates, and therefore the available water storage capacity, varies greatly among soils. The water storage capacity is positively correlated with depth of wetting and the depth of the wet front can be predicted from the depth at which the total soluble salt content (TSS) is greatest.

The area studied here was a paddock of a grazing experiment on the CSIRO Lansdown field station, near Townsville, Queensland. The vegetation of the paddock showed a pronounced mosaic pattern. The soils of the station are typical of the region (Murtha & Crack 1966) so that any vegetation-soil relations found in this area may be relevant on the regional scale.

MATERIALS AND METHODS

The study area was within a 4·8 ha paddock which had carried between two and four beef cattle continuously for at least seven years prior to this study, and which carried four cattle during the study. The flora consisted of perennial grasses (PG), primarily *Heteropogon contortus*, but also *Chrysopogon fallax* and *Bothriochloa decipiens* var. *cloncurrensis;* annual grasses (AG) primarily *Chloris barbatus* and *Digitaria ciliaris*, and lesser amounts of *Dactyloctenium aegypticum*, and *Brachiaria milliformis;* Townsville stylo (TS); and a few forbs (F) including *Sida acuta*, *S. cordifolia*, and *S. rhombifolia*.

The actual area studied was 4·0 ha and excluded a 10 m wide perimeter strip around the paddock. A vertical aerial photograph of the mosaic pattern was taken in March 1971 (Plate 1a). In April, herbage samples were taken on a 10 m grid (19 × 23 = 437 sites) using quadrats 60 × 60 cm, cut at a height of 2–3 cm. Samples were hand sorted into perennial grass, annual grass, Townsville stylo, and forbs, dried at 65° C and weighed. Topography was surveyed on a 20 m grid. Elevation was measured above the lowest recorded point.

Soils were described and sampled on a 20 m grid (10 × 12 = 120 sites) from undisturbed cores 10 cm in diameter. The vertical sampling interval was 10 cm. However, since the A and B horizons differ so markedly, they were treated as different soils, with the soil surface serving as the sampling datum for the A horizon and the top of the B as the sampling datum for that horizon. If the lowest A horizon sample was >5 cm it was treated as a full increment; if it was <5 cm it was included in the previous increment. Where possible, profiles were sampled to 150 cm, but commonly this was prevented by the occurrence of coarse alluvial gravel.

Total soluble salts (TSS), pH and available phosphorus were determined on all samples of the 120 cores. Profiles were then classified into four groups, on the basis of high *v.* low maximum TSS and of shallow *v.* deep occurrence of this maximum. Five profiles were then chosen from each group for additional laboratory analyses, e.g. exchangeable basic cations and particle size distribution.

Total soluble salt content and soil pH were both measured on 1 : 5, soil : water suspensions at 25° C by electrical conductivity and glass calomel electrodes respectively. Exchangeable sodium percentage was determined by method B of Loveday, Beatty & Norris (1972), and particle size distribution by a pipette method, after dispersion with Calgon and NaOH. Available P was determined after extracting with 0·01 N H_2SO_4 for 16 h (Probert 1975).

The map contours of Figs 2(a), (b) and (c) were determined by fitting a surface through the data matrices using a least squares computer algorithm and were plotted automatically. In Fig. 2(a), only yield data corresponding to the 120 soil and elevation sample sites (Figs 2(b), (c), and (d)) were used.

Plate 1b is based on data from all 437 vegetation quadrats. Each quadrat was classified according to its dominant or co-dominant components. (Dominance was arbitrarily defined as > 67% PG, AG, TS, or F; co-dominance as >90% contributed by the two highest-yielding components, each <67%.) Similarly, mapping units were defined by single component dominance (dominant in >67% of quadrats) or co-dominance (two largest components together dominant or co-dominant in >90% of quadrats but each <67%).

RESULTS

Vegetation patterns

The areas of darkest tone in Plate 1a are those of tall, perennial bunch grass; the lightest areas are nearly bare ground; areas of intermediate tone and smooth texture are predominantly Townsville stylo and annual grass. Areas of rough texture indicate the presence of tall tussocks of perennial grass in the shorter Townsville stylo sward. Plate 1b and Fig. 2(a) depict a generalized picture of variation in botanical composition and total yields respectively. The areas of highest yields correspond closely to those dominated by perennial grass. Bare ground is not present in Plate 1b because all quadrats contained at least a small amount of vegetation. Bare areas (nil yield) are present in Fig. 2(a) but their existence and their imperfect correspondence to 'bare' areas in Plate 1a is due to the rounding and averaging effects of fitting a smooth surface through the data.

Soil variation

Soil profile measurements of representative samples of three of the four profile groups are presented in Fig. 1. All three soils have an abrupt transition from a sandy loam A horizon to a clayey B horizon. All have surface pH's of 5·5–6·0 and a maximum pH in the B horizon >9·0. Exchangeable sodium percentages (ESP), an important factor in permeability, differed markedly among sites; it was low in the A horizon at site 3, increasing to a maximum of 15 at 120 cm depth. The amount of exchangeable sodium in the A horizons was greater at sites 2 and 1, where the maxima in the B horizon were greater than 40. Profiles of TSS paralleled those of ESP; this also occurs in a wider range of similar soils (McCown *et al.* 1976). On the basis of the cited work, the amount of water stored in the subsoil would be greatest at site 3 and least at site 1.

The TSS profiles can be used to classify the soils, since they compare favourably with ESP in discriminating sites and are inexpensive. Four variables have been chosen to characterize TSS profiles; the maximum TSS concentration in the profile; the depth to this maximum (actually to 0·9 maximum, since the last 10% rise occurs over considerable depths and therefore gives rise to large errors); the depth to the zone of rapid rise in TSS; and the depth to an arbitrary threshold concentration (0·1%), which appears to have good discriminatory value.

A number of soil variables were intercorrelated (Table 1), especially variables 3–6 which characterise the TSS profiles. A notable exception was the low correlation between

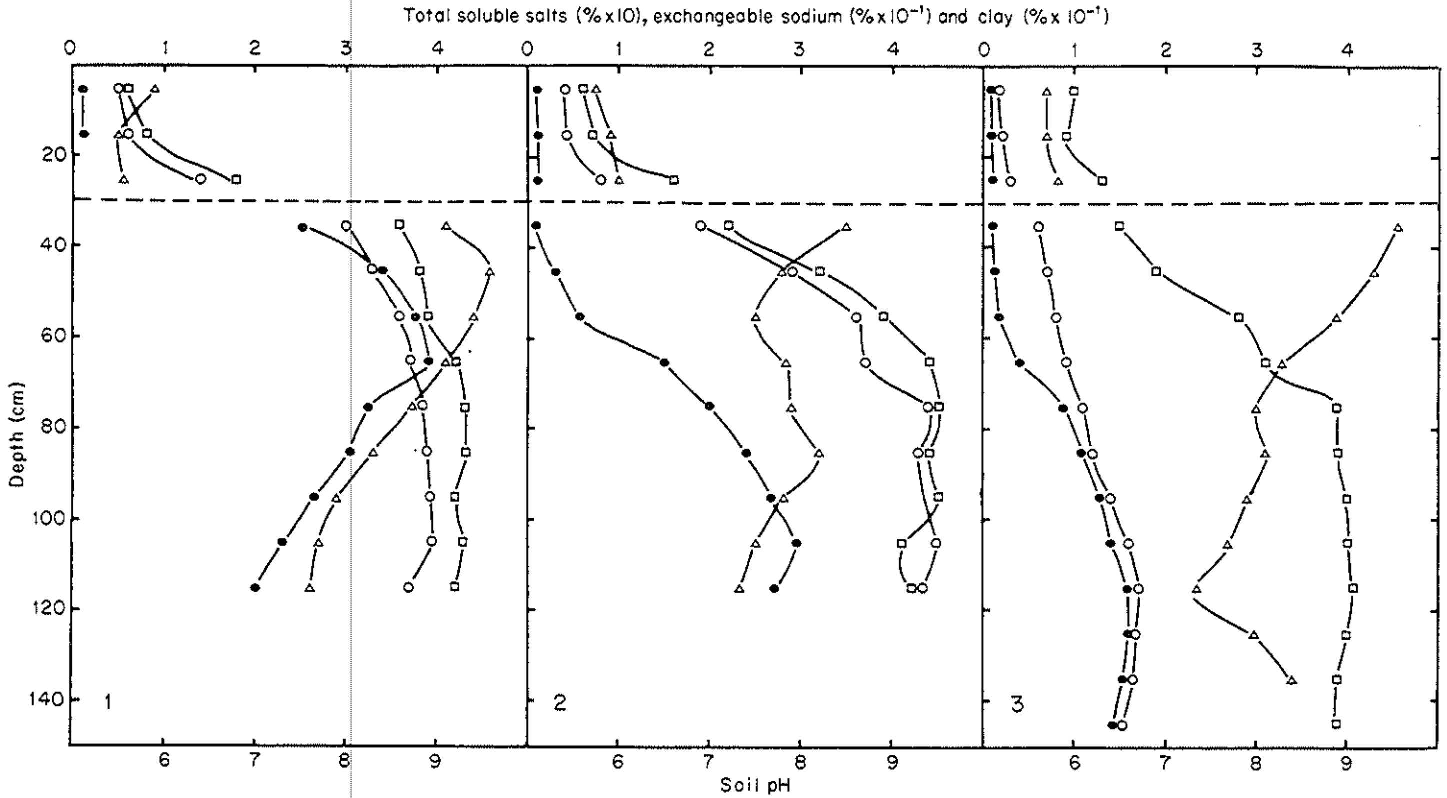

FIG. 1. Profiles of total soluble salts (●), exchangeable sodium (○), percentage clay (△), and pH (□) for sites 1, 2 and 3 indicated on Plate 1 and Fig. 2. The horizontal pecked line indicates the interface between the A and B horizons.

Table 1. *Correlation coefficients between eleven variables and five vegetation variables (data for* 120 *sites)*

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1. Relief	1·00														
2. Depth to B horizon	0·07	1·00													
3. Maximum TSS	−0·02	−0·17	1·00												
4. Depth to 0·9 max. TSS	0·09	0·28†	−0·10	1·00											
5. Depth to TSS rise	0·02	0·32‡	−0·71‡	0·45‡	1·00										
6. Depth to TSS = 0·1%	0·08	0·29†	−0·77‡	0·48‡	0·82‡	1·00									
7. Maximum pH	0·14	−0·31‡	0·31‡	−0·08	−0·25†	−0·20*	1·00								
8. Depth to 0·9 max. pH	−0·17	0·45‡	−0·24†	0·48‡	0·44‡	0·44‡	0·06	1·00							
9. Depth to pH = 8	−0·16	0·51‡	−0·49‡	0·55‡	0·63‡	0·59‡	0·51‡	0·68‡	1·00						
10. Depth to gravel	0·04	0·21*	0·18	0·40‡	0·02	0·11	0·11	0·30†	0·22*	1·00					
11. Available P	0·15	−0·06	0·03	0·04	0·08	0·07	0·05	−0·04	−0·04	−0·06	1·00				
12. Townsville stylo yield	0·12	0·21*	0·14	0·01	−0·11	−0·22*	0·07	0·01	−0·07	−0·03	−0·06	1·00			
13. Perennial grass yield	−0·04	0·08	−0·48‡	0·17	0·42‡	0·50‡	−0·33‡	0·18*	0·44‡	0·03	−0·07	−0·49‡	1·00		
14. Annual grass yield	−0·04	−0·24†	0·24†	−0·13	−0·24†	−0·19*	0·21*	−0·19*	−0·33‡	−0·05	−0·09	0·11	−0·37‡	1·00	
15. Forb yield	0·15	−0·05	0·00	0·00	−0·04	0·04	0·13	−0·15	−0·14	−0·05	0·30‡	−0·07	−0·18	0·01	1·00
16. Total pasture yield	0·03	0·11	−0·49‡	0·18	0·42‡	0·51‡	−0·30†	0·15	0·41‡	0·01	−0·03	−0·24†	0·92‡	−0·24†	0·05

* $P < 0{\cdot}05$; † $P < 0{\cdot}01$; ‡ $P < 0{\cdot}001$.

maximum TSS (3) and depth to 0·9 maximum TSS (4). These two variables might be expected to be highly correlated (Greene 1928; McCown *et al.* 1976) but the presence of course gravel in this study did not allow sufficiently deep sampling to measure the true maximum TSS. In spite of this lack of correlation, there is considerable evidence that the salt bulge was closer to the soil surface in more saline soils (e.g. Fig. 1).

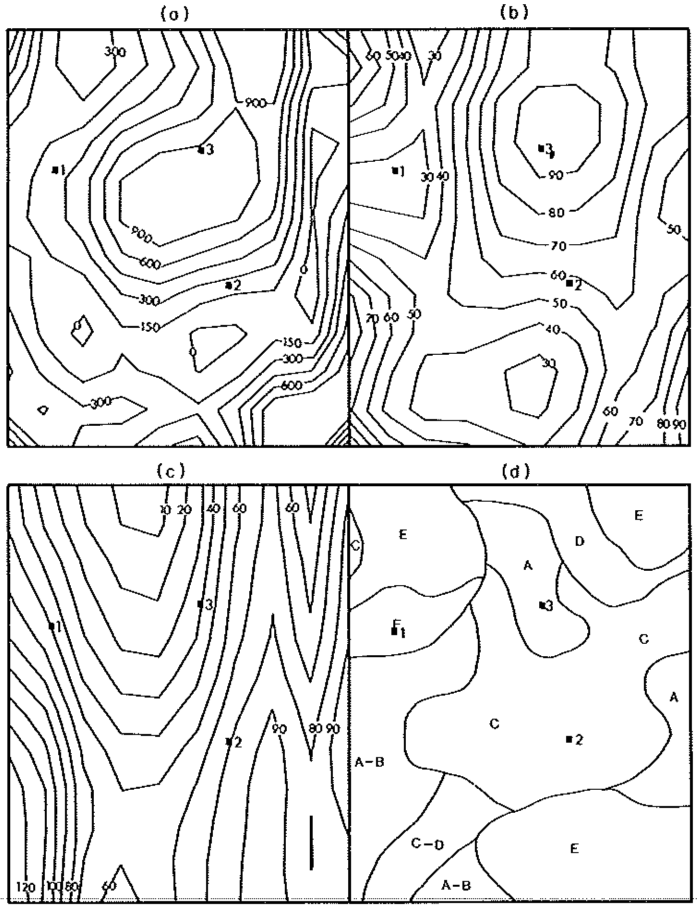

FIG. 2. Maps of vegetation and soils, based on samples from a 20 m grid. (a) Yield isopleths (g m^{-2}); (b) isopleths of depth to 0·1% TSS; (c) topography (elevation (cm) above lowest point measured); (d) major soil units (see Table 3). The numbered squares refer to locations of sample profiles shown in Fig. 1.

The depth to the B horizon was significantly correlated with all other depth parameters (4–6, 8–9) (Table 1). This is not surprising since the latter depths are measured from the soil surface and include the depth to the B horizon, but there is further theoretical reasons to expect these correlations. The total pore space in the A horizon determines the volume of water that is retained and therefore determines the leaching of salts down the profile.

The areal patterns of variation of three soil attributes are shown in Fig. 2. There is

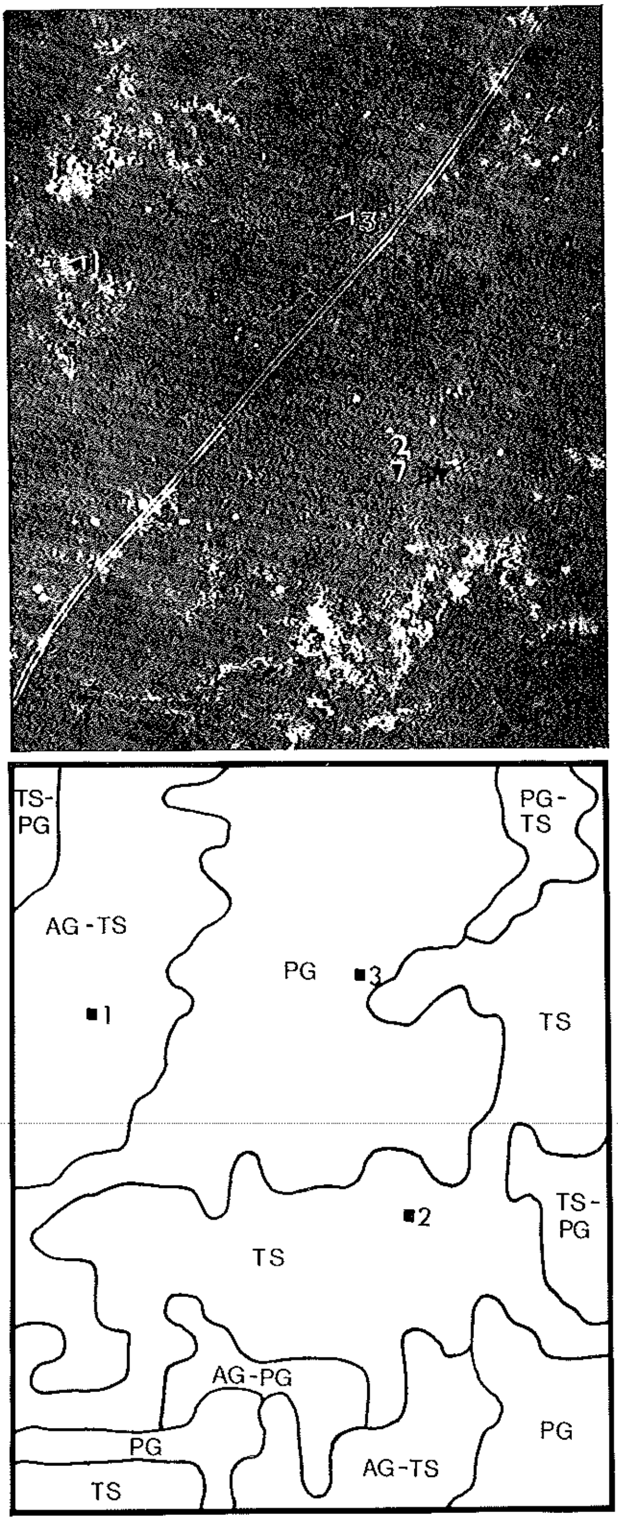

PLATE 1. (a). Vertical aerial photograph of study area. Numbers refer to location of sample profiles shown in Fig. 1. (1, bare soil; 2, dominantly Townsville stylo; 3, dominantly perennial grass). (b). Major vegetation units based on quadrats harvested on 10 m grid. (PG, perennial grass; AG, annual grass; TS, Townsville stylo).

little similarity between the soil type map (Fig. 2(d)), based on principal profile forms (Northcote 1971), and the map of depth to 0·1% TSS (Fig. 2(b)); neither of these maps relates closely to the topographic map (Fig. 2(c)).

Relations between vegetation and soil

Since it is generally considered that physical conditions of the A horizon are more favourable than the B, a positive correlation between depth to B and yield might be expected. The correlation was not significant for total yield but was significant ($P<0{\cdot}05$) for Townsville stylo. When the A horizon was shallow, annual grasses predominated so there was a negative correlation between depth to B and annual grass yield.

Although there was considerable variation in topography in this paddock (Fig. 2(c)), resulting in run-off and run-on areas, there was no significant correlations between elevation and soil or vegetation parameters.

There was a close similarity in correlation coefficients between vegetation variables and TSS on the one hand and pH on the other (Table 1). Under these conditions it seems that pH may be used in place of TSS with the possible advantage that field measurements are more practical.

Table 2. *Correlations between the canonical variables and the original vegetation and soil variables*

	Canonical variable	
	I	II
Vegetation variables		
Perennial grass yield	−0·99	n.s.*
Townsville stylo yield	0·45	−0·70
Annual grass yield	0·39	0·62
Soil variables		
Depth to TSS = 0·1%	−0·84	n.s.
Maximum TSS	0·80	n.s.
Depth to pH = 8	−0·72	−0·47
Depth to TSS rise	−0·70	n.s.
Maximum pH	0·53	n.s.
Depth to 0·9 max pH	n.s.	−0·33
Depth to B horizon	n.s.	−0·74

* Not significant at $P=0{\cdot}001$. Other vegetation and soil variables not included in this table are also not significant at $P=0{\cdot}001$

Perennial grass yield was positively correlated with depth to TSS rise and with the depth to 0·1% TSS, but negatively correlated with maximum TSS concentration.

The yield of stylo, annual grass, and forbs tended to be negatively correlated with yield of perennial grasses (Table 1). Consequently correlation coefficients between these vegetation components and any soil variable were of the opposite sign to those for perennial grass. This suggests an indirect effect of soil on vegetation components via competition with perennial grass. Apparently, the more favourable the soil conditions, the higher the yield of the robust perennial grasses, and the greater the suppression of the more ephemeral and/or smaller species.

Although these soils respond markedly to superphosphate fertilization, only the yield of forbs was significantly correlated with available P. This may reflect weed infestation of dunging sites. When maps of soil variables are compared with the vegetation maps (Plate 1a and 1b, Fig. 2(a)) there is an obvious similarity between the TSS pattern (Fig. 2(b)) and that in the vegetation. Areas of greatest 'depth to 0·1% TSS' are dominated by perennial grass and areas of shallow 'depth to 0·1% TSS' correspond closely to low-yielding areas with a scant cover, mainly of annual grass and stylo. In contrast, the vegetation pattern appears quite unrelated to the topography (Fig. 2(c)) or the distribution of soils classified morphologically (Fig. 2(d)).

Table 3. *Description of soil mapping units*

Soil	*P.P.F.	Surface soil	Sub-soil
A	Dy3.43	Dark greyish-brown sandy loam A_1, 2 to 4 cm thick over strongly bleached sandy loam A_2 horizon.	Abrupt change at 25–45 cm to mottled yellowish-brown and light brownish-grey heavy clay. At about 1 m this grades to dark grey heavy clay with moderate carbonate nodules
B	Dy3.43	As above	Abrupt change at 21–25 cm to heavy clay B horizons, otherwise as above
C	Dy3.43	Greyish-brown loamy sand to sandy loam A_1, 2–6 cm thick over a very strongly bleached loamy sand A_2. Moderate coarse gravel in base of A_2	Abrupt change at 30–40 cm to mottled yellowish-brown and greyish-brown gritty or sandy clay. Light gravels 1–10 cm size. Gradual change at 80–90 cm to mottled yellowish-brown and light grey sandy clay loam, light to moderate gravel. Carbonate nodules common from 50–60 cm
D	Dy3.43	As above	Abrupt change at 15–25 cm to gritty or sandy clay B horizons, otherwise as above
E	Dy2.43	Dark grey or brownish-grey sandy loam A_1, 2 to 5 cm deep over a strongly bleached sandy loam A_2	Abrupt change at 12–20 cm to greyish brown heavy clay. At 40-50 cm this may become faintly mottled (yellowish-brown) and there are moderate to high amounts of carbonate nodules from 60 cm
F	Dy2.43	As above	Abrupt change at 27–30 cm to heavy clay B horizons, otherwise as above.

* Principal Profile Form (Northcote 1971).

A canonical correlation analysis (Kendall 1975; Hotelling 1936) was performed to compare relationships among the four primary vegetation variables with relationships among the eleven soil variables; simple correlations were then calculated between the canonical variables and the original variables (Table 2). The first canonical variable accounted for 47% of the total variation and reflected the association between perennial grass yield and the depth to the arbitrary threshold value and the maximum values for both TSS and pH, and depth to the point of TSS increase (Table 2). The second canonical variable, which accounted for 28% of the total variation, represented for the vegetation variables a contrast between yields of Townsville stylo and annual grasses and, for the soil variables, principally represented depth to the B horizon, depth to pH 8 and depth to maximum pH.

Vegetation pattern in the study area has been monitored over five seasons and has been found to vary, but in a manner quite consistent with the results reported (McCown, unpublished). As a result of two consecutive dry years, there was a retreat of the boundaries of the main perennial grass areas and an enlargement of bare-soil areas. After a succession of favourable seasons, perennial grass dominant areas were larger and formerly bare areas had a dense ephemeral annual grass cover. This substantiates the interpretation of soil variables most highly correlated with vegetation as being of hydrological importance.

DISCUSSION

Small scale mosaic patterns in grassland vegetation are common in subhumid climates. Where water supply is sub-optimal, any factor which causes differences in the entry or retention of water to soils contributes to differences in the vegetation. As a result, even a small variation in topography can produce large effects on the vegetation (Warren Wilson & Leigh 1964; Torssell 1973). In this study there was considerable variation in topography (Fig. 2(c)) but no apparent effect on the vegetation. Instead, the vegetation pattern seems to be due primarily to variation in subsoil permeability. If the vertical distribution of total soluble salts is interpreted as a product of leaching over many years, the more permeable the soil, the less salt will be found high in the profile. The perennial grass tended to occupy the more permeable soils, which store sufficient water for survival in long dry seasons. In contrast, the annual legume and annual grasses are dormant during the long dry season, so their distribution is not determined by soil permeability. The annuals would presumably produce higher yields on the more favourable sites, but are unable to compete with the perennial grass in these conditions.

It is unlikely that soil physical factors were the only factors contributing to the pattern development in the vegetation. Ritson *et al.* (1971) have shown that botanical composition of this vegetation is influenced strongly by grazing pressure; perennial grass declines, and annual grass and Townsville stylo increase with heavy stocking. In this study, the stocking rate was constant, but the distribution of grazing pressure over the area may be highly variable. In the wet season, grass growth greatly exeeds intake, so a large quantity of low quality grass accumulates and stylo is grazed only lightly (M. J. Playne, personal communication), cattle then tend to graze the regrowth of areas grazed earlier and so produce areas of high and low grazing pressure. Considering these influences on the dry matter distribution, it is easy to see why correlations of yields of vegetation components with soil variables were not great.

The finding that the pattern of soil units differed so greatly from those of other major soil and vegetation variables has important implications for soil survey of pastoral lands in this region. It would appear that laboratory measurements of soil conductivity, or possibly field measurements of soil pH or conductivity, are the most relevant soil measurements. The practicality of this, however, depends upon the objective and scale of survey. Further study of this aspect is required.

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