STRATEGIES FOR DRYLAND PASTURE MANAGEMENT — A REVIEW

D.J. Barker
Grasslands Division, DSIR, Palmerston North
A.C.P. Chu
Agronomy Department, Massey University, Palmerston North

ABSTRACT

The annual amount and distribution of rainfall and evapotranspiration vary throughout New Zealand. As a consequence, and because of the unavailability of irrigation, pasture production in dryland areas suffers as a result of water deficits. Published work suggests there are some possibilities for mitigating water deficits by management options.

The 51 papers reviewed showed a deficiency in quantitative descriptions of both a) the relationship between pasture growth and soil moisture and b) factors which might modify this response. Furthermore, the effects of grazing management on soil moisture were equivocal; reports of a general relationship between increasing herbage mass (or LAI) and increasing evapotranspiration were supported by evidence of conserved soil moisture under short pastures but were contradicted by evidence showing the benefits of long pasture as a moisture conserving mulch. Furthermore, in hill country, benefits of soil moisture conservation under short pastures were likely to be negated by a greater runoff. It was concluded that any benefits of grazing management on soil moisture, and hence pasture and animal production, were likely to be small compared to other management options such as alternative pasture species, lime, earthworms and wind shelter.

INTRODUCTION

The annual amount and distribution of rainfall and evapotranspiration (ET) vary throughout New Zealand. As a consequence and because of the unavailability of irrigation, pasture production on dryland areas suffers as a result of water deficits. Published work suggests there are possibilities for mitigating water deficits in dryland using various management options.

This review considers strategies for dryland pasture management within the zone where greatest scope for benefits from such strategies exists. "Obligate" dryland, where perennial pasture survival is marginal, will not be considered. Water deficits in dryland occur with annual regularity and are considered distinct from water deficits during drought which occur as variation from the seasonal norm.

Animal husbandry options (e.g. manipulation of feeding level and stocking rate) and financial management practises can also modify the influence of animal production and farm profitability respectively however discussion of these is beyond the scope of this review.

THE NATURE OF NEW ZEALAND DRYLAND

Dryland in New Zealand can best be defined as those regions where at some time of the year soil water content falls below a critical value, below which pasture production is restricted. A simple definition such as the absence of irrigation is inadequate, however by implication these areas receive no or inadequate irrigation. Dryland areas will therefore occur as some combination result of low annual rainfall (<1000 mm), high ET (>900 mm annual potential ET; McAneney and Kerr, 1984), high runoff and low water holding capacity soils (i.e. shallow or porous).

Quantification of the above definition is more difficult. McAneney and Judd (1983) found that yields were reduced linearly after the soil water deficit (SWD) exceeded a critical value of 38 mm. Smaller values (25-37 mm) are given by Hopewell (1958) for a clay loam. Other reported values are: 25-50 mm depending on the level of nitrogen fertiliser (Penman, 1962) and 100-125 mm for a relatively heavy loess (Scotter *et al.*, 1979; Barker, 1983). Although SWD may be a useful value within one soil type, clearly no single critical value can be given for all soil types. Measures of soil water potential (ψs) may be useful in this instance but are still of limited value since they show physiologically large gradients down the profile. Barker (1983) found that pasture growth slowed when ψs in the top 50 cm was lower (drier) than -0.1 MPa however ψs at 100 cm was similar to that at field capacity.

A third term, the percentage depletion of plant available soil water, can also be used. Irrigation scheduling systems commonly use 50% of plant available water as a trigger point for minimising the effect of water deficit on crop yield (Jamieson *et al.*, 1984), however this method has yet to be applied to pastures.

The actual loss of herbage yield will be a function of both the intensity and duration of water stress. Rickard (1960), Baars & Coulter (1974) and Scotter *et al.* (1979) obtained good relationships between annual (or seasonal) production and a time dependent parameter (i.e. time SWD exceeded a critical value of, 51 mm in the top 300 mm, 75 mm in the top 760 mm or 120 mm in the total profile, for the respective cases of Rickard, Baars & Coulter, and Scotter *et al.*). In each study, pasture growth is arbitrarily assumed to operate in an off/on manner above/below this critical point however McAneney and Judd (1983) found that production declined linearly beyond the critical point.

Better definition of the relationship between pasture growth rate and SWD(or ψs) is necessary.

Dryland areas considered by this review fall mainly within the zone of 50-100 mm of average annual water deficit identified by Coulter (1973). Further areas of localised dryland occur on the sunny faces of hill country. At the more severe extreme, obligate dryland is that where the survival of perennial temperate pasture grasses is marginal (Roberts, 1974). In such environments, production depends largely on annual plants and on times when the stress is not present. This upper limit to grass survival has not been described quantitatively but is probably in the region of 200-300 mm SWD (or $\psi s = -1.5$ to -2.5 MPa) for a period of 3 months.

GRAZING MANAGEMENT AND SOIL MOISTURE

Grazing management offers scope for manipulating soil moisture through evapotranspiration or runoff.

Evapotranspiration

The classical models for predicting ET are based on climate variables, assuming flat areas of well watered grass of uniform height completely shading the ground. In practice, these conditions are usually not met and factors such as species, plant density, height, rooting depth and stage of growth can influence the rate of ET (Gates and Hanks, 1967). Even in conditions where the assumptions are met, variations in the rate of moisture use have been large in pastures of different species at various heights (Mitchell and Kerr, 1966). Ritchie and Burnett (1971) found that ET increased for crops with LAI up to a critical value of about 3, beyond which point ET was unrelated to LAI. Although this has not been confirmed on permanent pastures, the fact that LAI for pasture can be less than 3 (Brougham, 1956) suggest some control of ET is possible by manipulation of herbage mass.

Goode (1956) found a difference between the development of SWD under long and short perennial ryegrass pasture. Long (uncut) grass depleted the available soil moisture reserve more than short (50-100 mm) grass for a 7 month period during spring to autumn. This difference was most pronounced at 45-90 cm soil depth. An almost negligible difference in the 0-45 cm zone may reflect the benefit of a surface mulch preventing soil evaporation. Yields were not presented.

Evans (1976) found for a ryegrass-white clover pasture that hard defoliation treatments (weekly grazing to 2.5 cm) resulted in a greater (wetter) soil moisture potential than lax treatments. Soil water contents were not presented. Rather than the expected ability of plants in the more favourable soil moisture conditions to produce, yield was unexpectedly greater in the lax management with a drier soil. Presumably continued ET from these deeper rooted pastures depleted the soil moisture store. Evans (1976) concluded that the effects of grazing management were smaller than those of different pasture species. Similarly, Jantti and Heinonen (1957) followed the effect of defoliation and soil moisture on grassland regrowth. Lax mowing of pasture (12 cm) depleted soil moisture faster than intermediate (4 cm) and hard (< 1 cm) defoliation however, as in Evan's (1976) case, yields were also greater in lax managements.

Mitchell and Kerr (1966) compared water use (as the mean daily difference in "available" water at the beginning and end of no-rainfall periods) in long (20-30 cm) or short (2.5-5.0 cm) swards of ryegrass or white clover. During 2 periods in summer the mean rate of water loss was 5.32, 2.89, 2.30 and 1.79 mm/day for tall ryegrass, tall white clover, short white clover and short ryegrass respectively. In addition Kerr (1974) demonstrated the benefit of a summer fallow conserving 61.5 mm of water compared to a paspalum pasture.

In summary therefore, water can be conserved by keeping pastures short. In the 2 studies that measured herbage production, water conservation was at the expense of a loss in herbage production. None of the studies demonstrated a yield advantage from stored water but none specifically investigated managements to exploit soil water. The limitation from removal of photosynthetic tissue in keeping pastures short has obviously modified the pasture growth response at more favourable soil moisture conditions.

In contrast to the above work, Brougham (1959) found that frequent hard grazings (grazing at 75 mm down to 25 mm) depleted gravimetric soil moisture more so than frequent lax grazings (grazing at 175 mm down to 75 mm) in a ryegrass and red and white clover pasture. The lax grazings were 24%, 9% and 7% wetter in the respective soil depths 10-75 mm, 75-150 mm and 150-225 mm, while at 225-300 mm depth differences were not significant. Neither bulk density nor soil moisture below 300 mm were measured. The mulch effect of the long pasture was of benefit to water conservation in the surface layer. A reduced yeild under hard grazing was attributed to lower soil moisture.

The contrast in response of soil moisture to grazing management arises probably as a consequence of the two processes of water loss from soil, namely transpiration and soil evaporation. In general transpiration increases with increasing herbage (mulch). The call of Kerr and McPherson (1977) to define satisfactorily the relative importance of transpiration and soil evaporation for pastures with a partial leaf cover has yet to be adopted.

Runoff

Catchment studies measuring runoff (stream flow), rainfall and evapotranspiration also give information on the influence of grazing management practices on pastures and the soil water balance. Lambert *et al.* (1985) found no effect of grazing management on runoff but high fertilised catchments (700 kg superphosphate/ha/a) had a lower (25%) runoff than low fertilised catchments (120 kg superphosphate/ha/a). This was attributed to greater ET under high fertiliser as the result of greater herbage accumulation rates and faster infiltration rates from a 24% greater earthworm mass. Changes in moisture storage were not measured. Specific management to maintain herbage mass might be expected to have less runoff and improved water storage. Conversely, managements aiming to reduce

ET by keeping pastures short will lose more water through runoff. VanKeuren *et al.* (1979) measured runoff from cattle-grazed pastures finding that lax-grazed pasture had less runoff, greater infiltration rates and greater evapotranspiration than for harder grazing. The effects of soil moisture on pasture production were not considered however in hill country, opposing effects of evapotranspiration and runoff minimise any potential for the manipulation of soil moisture by grazing management.

GRAZING MANAGEMENT AND SUMMER PASTURE PRODUCTION

In addition to the effect of grazing management on soil moisture *per se* and therefore on production, grazing management will also influence other factors involved in a plant's response during water stress. Often these factors may modify the relatively elusive relationship between pasture growth and soil moisture and reverse the response observed.

Without doubt, short pastures produce less herbage than long pastures during water stress (Jantti & Heinonen, 1957; Brougham, 1959; Evans, 1976). In addition to the removal of photosynthetic tissue and the already discussed effects of soil moisture *per se*, this can also be attributed to:

a) reduced rooting depth. Hard, frequent grazing has been found to reduce plant rooting depth (Weinmann, 1948), reducing the available water supply to the plant and hence its ability to produce or survive. Davidson (1978) and Korte & Chu (1983) discussed the choice which must be made between managements to optimise top and root growth.

b) reduced plant available soil water. Defoliated plants draw less water from the soil since, with the leaves removed, water potentials cannot be lowered to the same extent as that for intact plants (Jantti and Kramer 1956). It follows therefore that, at similar soil water contents, shorter pastures will have a smaller reservoir of available water from which to draw and consequently reduced ability to produce.

c) depleted carbohydrate content. Plant carbohydrate reserves would be expected to be reduced with hard, frequent defoliations (Bommer, 1966). Recently, osmotic adjustments with soluble sugars have been observed as an adaptive response by some species to water stress (Turner and Begg, 1978; Jones *et al.*, 1981). It has not yet been demonstrated whether ryegrass shows this response but if it does, the lowering of plant carbohydrate content by defoliation would be expected to influence the osmotic response.

d) reduced tiller density. Lax infrequent (compared with hard frequent) defoliations during spring can reduce tiller density (Korte, 1981). Evidence of a positive relationship between yield and tiller density suggests that summer yield may be reduced by lax spring grazing. Korte and Chu (1983) found drought had a more severe effect on younger tillers and concluded that "to prepare a pasture for summer drought, spring management should encourage root growth and a higher tiller density". Barker *et al.* (1985a) found that spring managements that increased tiller density resulted in greater tiller density at the end of drought. However in dryland any benefit is unlikely to be in summer production but may be in the potential for faster recovery after drought. Similarly Vartha Hoglund (1983) concluded that if summer grazing does not bare the pasture for long periods, dryland is insensitive to a wide range of grazing managements. More important however is grazing management after summer drought.

e) the ratio of vegetative to reproductive tillers. Lax and infrequent grazing in spring will allow apical inhibition of tiller formation and development of grass flower heads. Pastures with a low ratio of vegetative to reproductive tillers are likely to have new tillers which are less mature and less likely to survive drought.

OTHER MANAGEMENT FACTORS

In addition to grazing management, other factors can be manipulated to influence soil moisture and pasture production.

Wind shelter

The benefit of wind shelter to pasture production is widely acknowledged (Marshall, 1967; Radcliffe, 1983), as are the benefits in reducing evaporation and increasing soil moisture, (Lynch *et al.*, 1980). Up to 60% improvement in annual dryland pasture production have been reported in the lee of shelter by Radcliffe (1985) which was attributed predominantly to reduced evaporation rates. Although this response only occurred in some zones in the lee of shelter and was offset in part by a depression of yield in the immediate vicinity of shelter, it nevertheless resulted in a net yeild advantage behind shelter. The evidence suggests benefits to pasture and animal production might be obtained by the more widespread use of shelter trees (Lynch and Donnelly, 1980).

Lime

The application of lime has been observed to increase the gravimetric water content on some soil types and although not specifically measured, this is proposed as the mechanism for observed lime responses in summer-autumn (During *et al.*, 1984). Little is known of the mechanism of this response or of the extent to which it interacts with the earthworm population. The rapid action observed by During *et al.* (1984) suggested that it was unlikely that a biological component was solely involved. It was further observed that there was a negative interaction of lime and superphosphate on soil moisture. Application of lime may interact positively with pasture species able to produce at marginal levels of soil moisture however the role of lime in soil water management remains uncertain.

Earthworms

The introduction of earthworms, (*Allolobophora caliginosa*) (Stockdill, 1966) and *A. longa* (Springett, 1984) has been shown to improve pasture production both in the presence and absence of lime (Stockdill, 1966). This response has been attributed to a number of factors including improved nutrient cycling and improved soil structure. It was found that the available soil moisture was increased by 18 mm largely as the result of a 17% greater water content at field capacity but only a slightly higher water content at -1.5 MPa. Infiltration rates were double and the root development greater where earthworms had been introduced (Stockdill, 1966). The role of earthworms in soil water management remains uncertain.

Pasture species

Legume and grass species are known to differ in their tolerance to drought. The species identified to have potential for dryland production are the legumes lucerne and subterranean clover and the grasses cocksfoot, prairie grass, tall fescue and phalaris (Hume and Fraser, 1985).

The advantages of dryland production from lucerne are acknowledged and on shallow stony Canterbury soils, lucerne can outyield pasture by 50% (White, 1982). Disadvantages of lucerne include its specific grazing management and susceptibility to insects and disease however this does not restrict its use on some 180,000 ha in New Zealand (Dunbier *et al.*, 1982).

Subterranean (sub) clover is also used widely in dryland especially in lower fertility areas such as hill country. Its annual habit gives it no advantage in summer production (Smetham, 1983) but rapid spring growth can result in it annually contributing as much or more herbage than white clover (McFarlane and Sheath, 1984).

The three grasses, cocksfoot (Jackson, 1974; Evans, 1976) phalaris (Rumball, 1980) and tall fescue (Brock, 1983) can survive and produce better under water stress than ryegrass however they have not been widely adopted in dryland areas. Evans (1976) found evidence to suggest cocksfoot did not draw water from a greater depth than ryegrass but rather that it could grow at a lower soil water potential. Previous problems with cocksfoot such as poor quality, erectness and consequent poor persistence under sheep grazing and susceptibility to stem and crown rust have been improved in a recent cultivar 'Grasslands Wana' (Rumball, 1982). This cultivar shows greater dry season production than ryegrass (Barker *et al.*, 1985b). 'Grasslands Maru' is the only phalaris cultivar bred in New Zealand although another cultivar 'Australian' is also on the New Zealand although another cultivar 'Australian' is also on the New Zealand List of Acceptable Herbage Cultivars. The value of phalaris is an extensive root system which both stabilises soil and ensures plant survival during its dormant state in summer. Maru shows some potential as a high producing pasture in Central Wairarapa dry hill country (Barker, unpubl.). Tall fescue is a species described as having improved summer-autumn production and persistence relative to ryegrass (Brock, 1983). This advantage only shows up in areas prone to long periods of moisture stress and the greater the stress, the greater is the relative advantage (Brock 1983). Commercial quantities of 'Grasslands Roa' tall fescue seed only became available in 1983 so it has not yet been widely used as a pasture grass.

CONCLUSIONS

1. Other factors are likely to be more important than soil moisture *per se* in governing the response of pastures to grazing management during water stress.
2. Grazing management to keep pastures short in summer can conserve soil moisture but probably at the expense of some loss of production.
3. In hill country, the benefits of soil moisture conservation in spring under short grazing are likely to be negated by greater runoff.
4. Possible benefits of optimum (lax) grazing management in dryland are likely to be smaller than benefits of other management options such as wind shelter, lime, earthworms or other species.
5. **Quantitative** relationships between pasture growth and soil moisture, and the effects of various factors on these relationships should be better defined.

REFERENCES

Baars, J.A., Coulter, J.D. 1974. Soil moisture and its influence on pasture production in the Waikato. *Proceedings N.Z. Grassland Association 35:* 197-203.

Barker, D.J. 1983. The effects of summer moisture stress and its interaction with spring cutting managements on the production and persistence of a ryegrass (*Lolium perenne* L.) sward. M.Ag.Sc. thesis, Massey University, Palmerston North.

Barker, D.J., Chu, A.C.P., Korte, C.J. 1985a. Some effets of spring defoliation and drought on perennial ryegrass swards. *Proceedings N.Z. Grassland Association 46:* 57-63.

Barker, D.J., Lancashire, J.A., Meurk, C. 1985b. 'Grasslands Wana' cocksfoot - an improved grass suitable for hill country. *Proceedings N.Z. Grassland Association 46:* 167-172.

Bommer, D.F.R. 1966. The influence of cutting frequency and nitrogen level on the carbohydrate reserves of 3 grass species. *Proceedings X International Grassland Congress:* 156-160.

Brock, J.L. 1983. 'Grasslands Roa' tall fescue: A review. *Proceedings N.Z. Grassland Association 44:* 74-80.

Brougham, R.W. 1956. Effect of intensity of defoliation on regrowth of pasture. *Australian Journal of Agricultural Research 6:* 377-387.

Brougham, R.W. 1959. The effects of frequency and intensity of grazing on the productivity of a pasture of short-rotation ryegrass and red and white clover. *N.Z. Journal of Agricultural Research 2:* 1232-1248.

Coulter, J.D. 1973. A water balance assessment of the New Zealand rainfall. *Journal of Hydrology (N.Z.) 12:* 83-91.

Davidson, R.L. 1978. Root systems - the forgotten component of pastures. *In* "Plant Relations in Pastures" Ed J.R. Wilson. CSIRO, Canberra. pp. 86-94.

Dunbier, M.W., Wynn-Williams, R.B., Burnett, P.A. 1982. Lucerne in the 70's *In* "Lucerne for the 80's" Ed R.B. Wynn-Williams. Special Publication No. 1, Agronomy Society of N.Z. pp 3-7.

During, C., Jackson, B.L.J., Dyson, C.B. 1984. Lime effects on hill country 1. Effect of lime and monocalcium phosphate on soil moisture. *N.Z. Journal of Agricultural Research 27:* 383-387.

Evans, P.S. 1976. Root distribution and water-withdrawal patterns of some crop and pasture species. Proceedings of Soil and Plant Water Symposium, Palmerston North, May 1976. pp. 186-190.

Gates, D.M., Hanks, R.S. 1967. Plant factors affecting evapotranspiration in "Irrigation of Agricultural Lands". Eds. Hogan, Haise and Edminster. American Society of Agronomy Monographs No. 11. pp. 506-521.

Goode, J.E. 1956. Soil moisture deficits developed under long and short grass. East Malling Research Station -Annual Report 43. pp. 64-68.

Hopewell, H.G. 1958. Sprinkler irrigation of pastures in the North Island. *N.Z. Journal of Agriculture 96:* 106-110.

Hume, D.E., Fraser, T.J. 1985. Establishing and managing recent cultivars in arable dryland pastures. *In* "Using Herbage Cultivars". Eds. R. Burgess and J. Brock. N.Z. Grasslands Association pp. 45-50.

Jackson, D.K. 1974. The course and magnitude of water stress in *Lolium perenne* and *Dactylis glomerata. Journal of Agricultural Science, Cambridge. 82:* 19-27.

Jamieson, P.D., Wilson, D.R., Stoker, R., Farrant, P. 1984. Irrigation management - Water budgeting for Spray Irrigation. Aglink FPP274, MAF, Wellington.

Jantii, A., Kramer, P.J. 1956. Regrowth of pastures in relation to soil moisture and defoliation. *Proceedings 7th International Grassland Congress:* 33-44.

Jantii, A., Heinonen, R. 1957. Effect of defoliation and soil moisture on grassland regrowth. *Journal British Grassland Society 12:* 56-61.

Jones, M.M., Turner, N.C., Osmond, C.B. 1981. Mechanisms of drought resistance in "Physiology and Biochemistry of Drought Resistance" 15-37 eds Paleg, L.G. and Aspinal, D. publ. Academic Press.

Kerr, J.P. 1974. Evaporation from a drying soil Proceedings Agronomy Society of N.Z. 4: 30-33.

Kerr, J.P., McPherson, H.G. 1977. Evapotranspiration and physiological responses to water stress of several pasture and crop species. *Proceedings N.Z. Grassland Association 39:* 70-78.

Korte, C.J. 1981. Studies of late spring grazing management in perennial ryegrass dominant pasture. Ph.D thesis, Massey University, Palmerston North.

Korte, C.J., Chu, A.C.P. 1983. Some effects of drought on perennial ryegrass swards. *Proceedings N.Z. Grassland Association 44:* 211-216.

Lambert, M.G., Devantier, B.P., Nes, P., Penny, P.E. 1985. Losses of nitrogen, phosphate and sediment in runoff from hill country under different fertiliser and grazing management regimes. *N.Z. Journal of Agricultural Research 28:* 371-379

Lynch, J.J., Elwin, R.L., Mottershead, B.E. 1980. The influence of artificial windbreaks on loss of soil water from a continuously grazed pasture during a dry period. *Australian Journal of Experimental Agriculture and Animal Husbandry 20:* 170-174.

Lynch, J.J., Donnelly, J.B. 1980. Changes in pasture and animal production resulting from the use of windbreaks. *Australian Journal of Agricultural Research 31:* 967-979.

Marshall, J.K. 1967. The effect of shelter on the productivity of grasslands and field crops. *Field Crop Abstracts 20:* 1-14.

McAneney, K.J., Judd, M.J. 1983. Pasture production and water use measurements in Central Waikato. *N.Z. Journal of Agricultural Research 26:* 7-13.

McAneney, K.J., Kerr, J.P. 1984. "Environmental inputs to Agronomic Research - Guidelines". MAF, Wellington.

McFarlane, M.J., Sheath, G.W. 1984. Clover - What types for dry hill country? *Proceedings N.Z. Grassland Association 45:* 140-150.

Mitchell, K.J., Kerr, J.P. 1966. Differences in rate of use of soil moisture by stands of perennial ryegrass and white clover. *Agronomy Journal 58:* 5-8.

Penman, H.L. 1962. Woburn irrigation 1951-59. II. Results for grass. *Journal of Agricultural Science, Cambridge, 58:* 349-364.

Radcliffe, J.E. 1983. Grassland responses to shelter - a review. *N.Z. Journal of Experimental Agriculture 11:* 5-10.

Radcliffe, J.E. 1985. Shelterbelt increases dryland pasture growth in Canterbury. *Proceedings N.Z. Grassland Association 46:* 51-56.

Rickard, D.S. 1960. The occurrence of agricultural drought at Ashburton, N.Z. *N.Z. Journal of Agricultural Research 3:* 431-441.

Ritchie, J.T., Burnett, E. 1971. Dryland evaporative flux in a subhumid climate: II Plant influences. *Agronomy Journal 63:* 56-62.

Roberts, K.L. 1974. Development of a dryland farm. *Proceedings N.Z. Grassland Association 36:* 39-44.

Rumball, W. 1980 *Phalaris aquatica* cv. 'Grasslands Maru'. *N.Z. Journal of Experimental Agriculture 8:* 267-271.

Rumball, W. 1982. 'Grasslands Wana' cocksfoot (*Dactylis glomerata* L.). *N.Z. Journal of Experimental Agriculture 10:* 51-52.

Scotter, D.R., Clothier, B.E., Turner, M.A. 1979. The soil water balance in a Fragiaqualf and its effect on pasture growth in Central New Zealand. *Australian Journal of Soil Research 17:* 455-65.

Smetham, M.L. 1983. Pasture legume species and strains in "Pastures and Pasture Plants". Ed. R.H.M. Langer. A.H. & A.W. Reed, Wellington. pp 85-127.

Springett, J.A. 1984. Earthworm introduction to improve pasture soils. *N.Z. Agricultural Science 18:* 61-64.

Stockdill, S.M.J. 1966. The effect of earthworms on pastures. *Proceedings N.Z. Ecological Society 13:* 68-75.

Turner, N.C., Begg, J.E. 1978. Responses of pasture plants to water deficits in "Plant Relations in Pastures" Ed. J.R. Wilson. CSIRO Canberra. pp. 50-66.

VanKeuren, R.W., McGuinness, J.L., Chichester, F.W. 1979. Hydrology. Chemical quality of flow from small pastured watersheds I. Hydrology. *Journal Environmental Quality 8:* 162-166.

Vartha, E.W., Hoglund, J.H. 1983. What is the make-up of a dryland pasture? *Proceedings N.Z. Grassland Association 44:* 204-210.

Weinmann, H. 1948. Underground development and reserves of grasses - a review. *Journal British Grassland Society 3:* 115-140.

White, J.G.H. 1982. Lucerne grazing management for the '80's. In "Lucerne for the '80s". Ed Wynn-Williams Special Publication No. 1, Agronomy Society of N.Z. p. 111-114.