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The annual variation in yield of pastures in the seasonally dry tropics of Queensland

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Summary—Dry matter yield of three vegetation-fertilizer combinations was found to be closely related to actual evapotranspiration estimated using simple water balance model. Cumulative actual evapotranspiration was estimated for each of 69 years of rainfall records and a description of annual variation in yields obtained using yield/actual evapotranspiration regressions.

An important early phase of pasture research in a region is the assessment of the yielding ability of promising species and mixtures over a range of fertilizer treatments. Although the common duration of such trials (2 to 4 years) is usually sufficient to reliably assess differences among treatments, in most of the Australian tropics such a small sample of years in insufficient to obtain a quantitative estimate of the year-to-year variation in yield. Such research, then, rarely provides an assessment of the main risk of a grazing enterprise in this environment.

One obvious way of correcting this deficiency is to conduct trials for longer periods. This has serious practical drawbacks. Firstly, maintenance of the original botanical composition and fertility level becomes increasingly difficult with time. Secondly, such long-term commitment of limited research resources seriously restricts the geographic scope of their application.

An alternative is to utilize the information in historical rainfall records to simulate the variation in production in a large sample of years. The aim of this paper is to demonstrate the feasibility of using standard rainfall data to provide estimates of year-to-year variability in yield of three pasture vegetation-fertility combinations at a site in north-eastern Queensland, Australia.

Materials and methods

Data were extracted for selected treatments within two experiments conducted at the C.S.I.R.O. "Lansdown" Research Station, 25 miles south of Townsville, Queensland (latitude 19°26'S). The mean annual rainfall in this region is about 875 mm, with nearly 80 per cent falling in December to March, a period of high evaporation. Experiment A was conducted on a solodized solonetz soil (Northcote Dy 3.43); experiment B on a levee soil classified as a red podzolic (Northcote Gn 3.15).

Experiment A measured the dry matter accumulation of natural grassland dominated by speargrass (*Heteropogon contortus*) into which Townsville stylo (*Stylosanthes humilis*) had been broadcast. Eight samples were taken at each harvest, which were spaced at three-week intervals throughout the three wet seasons from 1966 to 1968. A single terminal harvest was made in 1971.

Experiment B contained two treatments of improved pasture, Nunbank buffel grass (*Cenchrus ciliaris* cv. Nunbank) plus 600 kg ha^{-1} nitrogen applied as split dressings each month throughout the wet season. All plots received an annual basal dressing of superphosphate (750 kg ha^{-1} in the first year and 375 kg ha^{-1} in subsequent years), 63 kg ha^{-1} KCl, and zinc, copper, and molybdenum. Plots were harvested at four-week intervals throughout the wet season. The experiment had four replicates and continued for five wet seasons from December 1963 to May 1968.

In both experiments yield samples were cut 5 cm above ground level. In experiment B the remainder of the plots were mown after each harvest and the material removed, whereas in experiment A, this was

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done only annually before each wet season. Thus the yield data from experiment A consists of annual growth curves and that of experiment B, the summation of yields for successive four-week periods.

Results

Dry matter accumulation over time is shown in figures 1a, 2a and 3a. Time zero was a date when sufficient rain fell to initiate sustained growth of perennial grass. This date ranged from October 26 to January 2 during this five-year period. Whether a rainfall event was adequate to "open" a wet season was judged after about two weeks, but in retrospect, this could be determined by the simple criterion of 25 mm of rainfall in one week and 75 mm over two weeks. Even with a common starting date there were large differences among years in trends of dry matter accumulation, and in cumulative (figures 1a and 2a) and terminal yields (figure 3).

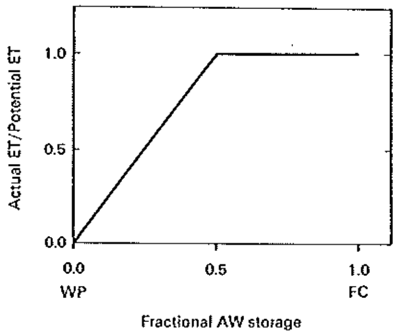
Although no soil water or plant water measurements were made, there was no doubt that the variable responsible for differences among years in figures 1a, 2a and 3a was water supply. Periods of visible water stress occurred in every wet season and always caused terminal cessation of growth. It would be expected, therefore, that an independent variable expressing the relative adequacy of water supply should account for more variation in the trends of dry matter accumulation.

The only data pertinent to the water climate, available for the duration of these trials, is daily rainfall. Figures 1b, 2b and 3b show the same dry matter plotted against cumulative rainfall. If one ignores 1967–68 data, the relation between yield and rainfall is considerably more general than with time. However, when all data are considered, the degree of departure of the 1967–68 data from the mean trend is sufficient to discourage any predictive use of the relation. In 1968, in the third harvest interval (broken line) 525 mm of rain in 12 days produced runoff of flood proportions. It can be concluded that unless the 1968 runoff event was an uncommon one, rainfall shows little promise as a predictor of dry matter production in this environment.

What is obviously needed is a means of accounting for large runoff occurrences, leaving a residual of "effective rainfall". Fortunately, the means for mathematically partitioning rainfall is readily available these days. One has the choice of a considerable number of agroclimatic and hydrological modelling computer programs. The decision of which one to use involves a trade-off between accuracy of prediction of effective rainfall and the simplicity and low cost of simple models requiring minimum input information and small computer time. (Effective rainfall is equal to actual evapotranspiration in this climate where the available water store is exhausted annually.)

In the present context, when input information is minimal, only simple models could be considered. The main aspects of the model used are as follows:

1. Input consists of weekly rainfall and weekly potential evapotranspiration (ET). The latter was taken as equal to Australian Tank evaporation.
2. The available soil water storage capacity is present, and stored water is assumed to be equally distributed throughout this single store.
3. Infiltration is unrestricted until storage equals storage capacity. Subsequent rainfall goes into a rainfall-excess term, which includes both through-drainage and runoff.
4. Actual ET is calculated as the product of input weekly potential ET and a soil water availability index determined by the following function:



A change of state of the model system occurs at time intervals of one week. First, actual ET is calculated. This loss is then deducted first from rainfall for that week and any balance from the soil water store. Any excess of rainfall over actual ET is added to storage. Storage in excess of capacity becomes runoff.

Soil water storage capacities have been reported for these soils (McCown 1971). In the water balance simulation, values of 80 mm for the solodized solonetz, which supported experiment A, and of 180 mm for the red podzolic soil, which supported experiment B, were used.

No evaporimeter data were recorded during most of the experimental period. Average weekly evaporation was estimated in the following way. Average

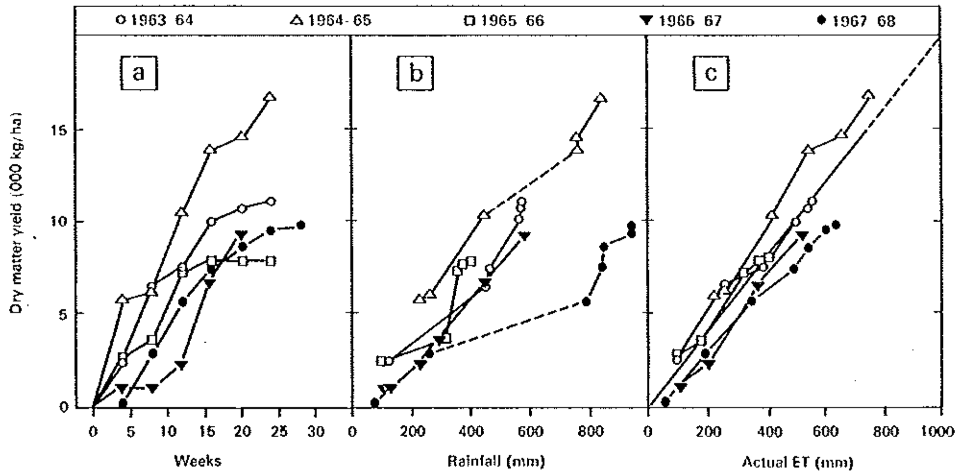


Figure 1—Cumulative yields of nitrogen-fertilized buffel grass cut at four-weekly intervals plotted against time, rainfall, and actual evapotranspiration.

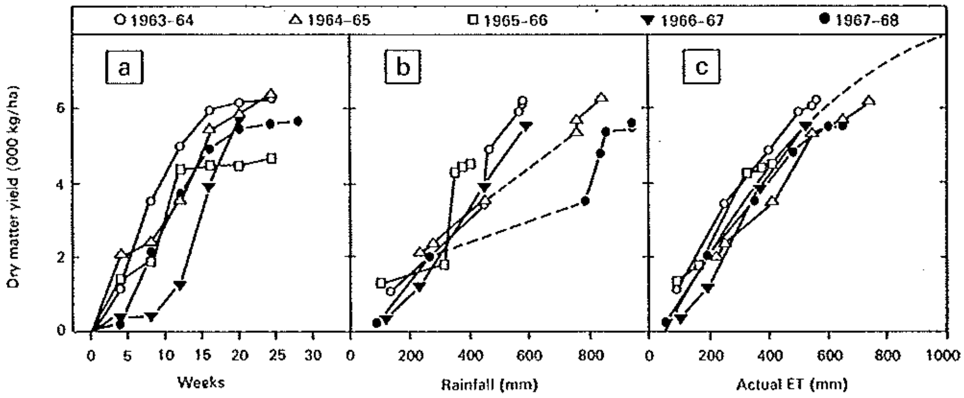


Figure 2—Cumulative yields of buffel grass—Townsville stylo cut at 4-weekly intervals plotted against time, rainfall, and actual evapotranspiration.

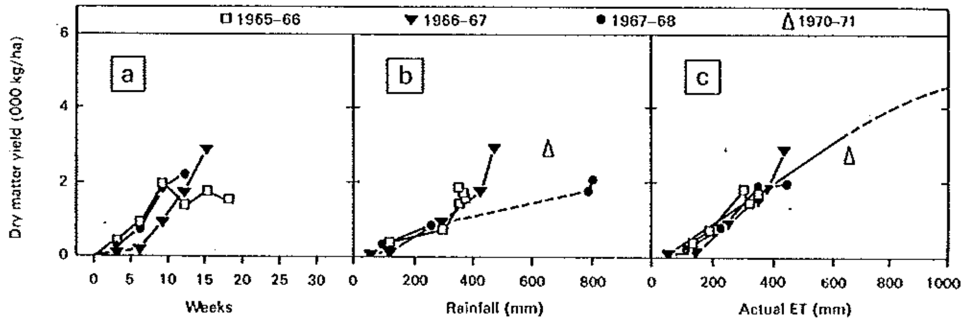


Figure 3—Serial yields of speargrass—Townsville stylo plotted against time, rainfall, and actual evapotranspiration.

monthly values for the site were obtained from published maps (Anon, 1968) interpolating linearly between isopleths where necessary. A smooth curve was drawn through the monthly values and weekly values determined by interpolation and weighting according to fractional time.

Simulated runoff (mm) for soils in both experiment A (80 mm Storage Capacity) and experiment B (180 mm Storage Capacity) are shown in the following table:

Year	*Expt. A*	*Expt. B*
1963–64	—	0
1964–65	—	72
1965–66	53	0
1966–67	56	0
1967–68	388	286

The periods where major runoff events occurred are shown as broken segments in figures 1b, 2b and 3b.

Figures 1c, 2c and 3c show the relation of cumulative dry weights of the three vegetation treatments to cumulative actual ET estimated by the water balance model. In each the solid portion of the long solid-broken line represents the least squares regression of yield on actual ET within the range of the experimental data. In figure 1c actual ET accounts for 86 per cent of the variation in yields; in figure 2c, 93 per cent; and in figure 3c, 88 per cent. The linear relation over the entire range of actual ET is to be expected in the treatment receiving regular inputs of the major limiting factor other than water, i.e. nitrogen: the linear extrapolation is shown by the broken segment. In the two grass-legume treatments, at the higher values of actual ET, yield of grass becomes progressively more limited by nitrogen and that of the annual legume, by reproduction and senescence. In these cases, extrapolation was made on the basis of maximum yields achieved in other experiments where water supply was non-limiting (R. L. McCown, unpublished data). When comparisons are made with figures 1b, 2b, and 3b, it is clear that the offending component of rainfall has been eliminated and that this new independent variable provides a regression that could be used for predicting yield from weather data with reasonable confidence.

Having established a statistical relation between dry matter production of the three vegetation treatments and actual ET, the next step is to derive values of the independent variable for each of a large number of years using historical data as input to the modelling program. A value for dry matter yield can then be estimated for each year from the regression of yield on actual ET.

Before proceeding, however, we must digress to the matter of the effect of variation in soils on the output of the water balance model. McCown (1973) reported on a study of the water balance and production on three soils with available water storage capacities of 80, 150, and 180 mm. The 80 mm and the 180 mm were the same soils as those used for the speargrass and buffel grass experiments in this paper. The soil water storage capacity parameter had a sizeable influence on the water regime in most years, but the relation between dry matter production of a vegetation treatment and actual ET was independent of storage capacity. To restrict the scope of this paper to the climatic influence on pasture variation, it seems justifiable in the light of the previous finding to use the regressions of figures 1c, 2c and 3c with independent variable values generated using a single common soil water storage capacity value. A value of 150 mm was chosen as being intermediate and one judged to approximate the median for soils of the region.

The values of simulated actual ET in each growing season from 1901 to 1972 are shown in figure 4. (1902 to 1963 are based on rainfall data from Woodstock, four miles from the experimental site). From these data, dry matter yield estimates were made using the regressions of figure 1c, 2c and 3c and cumulative probability curves constructed (figure 5). These show the per cent probability of getting less than a given yield in any season for each vegetation treatment.

Discussion

In this paper we have considered only one variable, water supply, as influencing dry matter production. This, of course, is a gross oversimplification of the real situation where growth rates were limited periodically by low radiation levels, the effects of defoliation, and by low temperature. The extent to which the water factor accounted for the annual variability in dry matter production indicates, however, that the inclusion of these other factors could produce, at best, only modest gain. In any case, inclusion could not contribute to a more accurate assessment of year-to-year variability in dry matter production due to the lack of historical temperature and radiation data at Woodstock. This limitation of weather data is typical of tropical Australia and most other tropical countries.

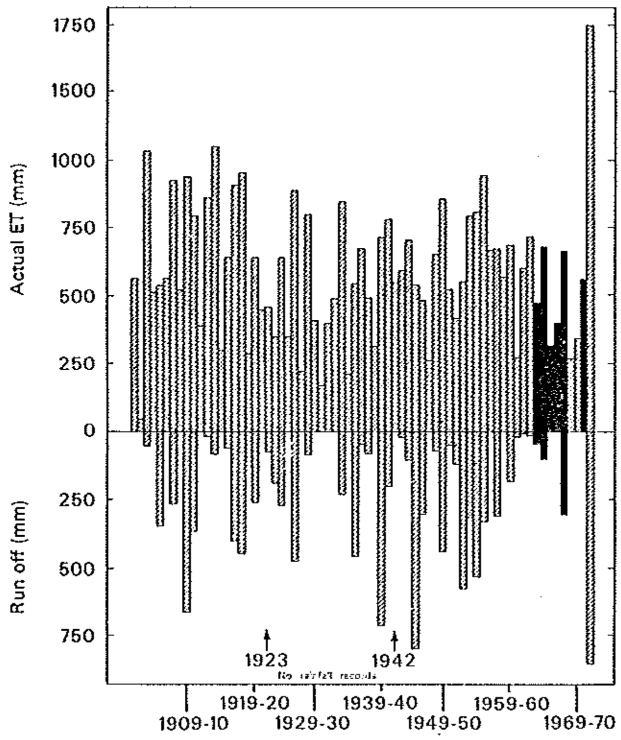


Figure 4—Histogram of simulated seasonal actual evapotranspiration and runoff from soil with available water storage capacity of 150 mm at the experimental site (1963–1972) and Woodstock, four miles away (1901–1962).

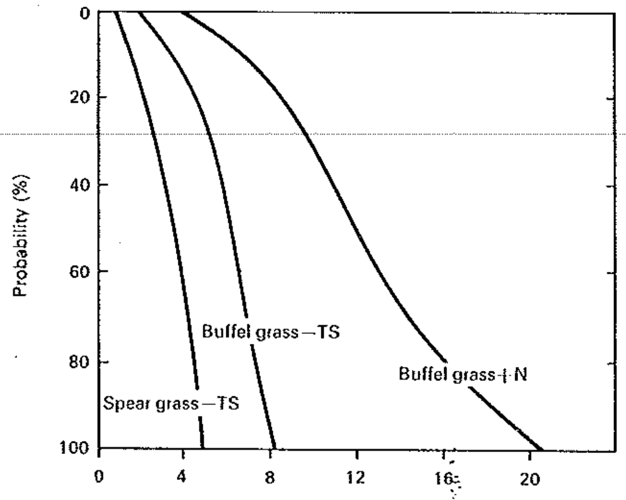


Figure 5—Cumulative probability distributions of annual yields of nitrogen-fertilized buffel grass, buffel grass—Townsville stylo, and speargrass—Townsville stylo.

Use of alternative variables for expressing the effect of water supply has been reviewed by Stanhill (1974). The use of actual ET has been widely adopted and has a sound theoretical basis. Thus, the utility of this variable in predicting yield is limited primarily by the availability of actual ET data. Although micrometeorological methods of measurement are possible, solution of the water balance equation provides the most practical means of estimating actual ET. Water leaves the soil only by ET and drainage. By careful logging of soil water contents under conditions where drainage is negligible, actual ET can be estimated accurately. A considerably more practical approach is to simulate the soil water balance using rainfall and evaporative demand as input to models of infiltration and water use and to use infrequent soil water measurements to test the output of the simulation. Value of the model system for predicting historical water balance depends on the degree of agreement of the simulated soil water with measured soil water.

Although soil water data for validation on these experiments was not available, such a validation was conducted for the same model system with similar vegetation and the same soils (McCown, 1973). The results showed good agreement between simulated and measured values of soil water.

Since actual ET, estimated using even the simplest models, is costly compared to rainfall, an evaluation of the size of the errors resulting from using rainfall is needed. In the experiments, in one year in five, sufficient runoff occurred to introduce a serious error, and moderately serious in another. The key question is, how often do such years occur? An answer can be obtained from figure 4. On a soil with a 150 mm available water store the runoff in 1967–68 was estimated as 320 mm (cf. earlier table for experimental soils). If we set 200 mm to be a maximum tolerable error due to undetected runoff, this is exceeded in one in three years (23 in 69). It is clear that the investment in the water balance simulation is required.

The types of vegetation studied in these experiments cover the spectrum of pasture improvement options from unfertilized resident speargrass + TS, through sown, high yielding, buffel grass + TS with ample superphosphate, to nitrogen fertilized grass. Evaluation of the economics of pasture improvement alternatives in climates with such large variation among years, requires the sort of information presented in figure 5. Interest focuses mainly on the risks of yields less than given amounts, in that with any stocking rate appropriate in a majority of years, there will always be wastage of feed in the best years. This interpretation minimises the importance of the extrapolated portions of the prediction relationships (figures 1c, 2c and 3c).

A great deal of agronomic effort has gone into conducting comparisons of genotypes and fertilizer treatments at multiple sites on the grounds that the amount of rainfall differs among these sites. It would seem that, in view of the large sample of years obviously needed to particularize site-yield relationships, measurements could be made at more sites for a shorter period if yield-ET regressions for treatments of interest were utilized. Annual yield variability could then be estimated using ET estimated from standard rainfall records at each site. This would allow a greater proportion of research resources to be expended on assessment of land parameters such as soil type. This application is especially important in agriculturally underdeveloped regions where there is little heritage of grazier or farmer experience that can be used for evaluating land productivity.

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